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USAAVLABS TECHNICAL REPORT 67-74

FEASIBILITY OF BURNING EMULSIFIED FUEL IN A 7LM100 ENGINE

By

W. W. Stockton

C. M. Olsen

February 1968

**U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA**

**CONTRACT DAAJ02-67-C-0038
FLIGHT PROPULSION DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO**

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This report was prepared by General Electric Company, Cincinnati, Ohio, under the terms of Contract DAAJ02-67-C-0038. It consists of a study to determine the feasibility of burning emulsified JP-4 fuel in a GE 7LM100 gas turbine engine.

The results of this study indicate that it is feasible to operate the 7LM100 engine on emulsified JP-4 fuel. Several areas in which further research is needed are brought out.

The information in this report will be utilized in the pursuance of further research in the area of fuel emulsions.

Project 1F121401A529
Contract DAAJ02-67-C-0038
USAAVLABS Technical Report 67-74
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By

W. W. Stockton
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Prepared by

Flight Propulsion Division
General Electric Company
Cincinnati, Ohio

For

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ABSTRACT

Much investigation and aircraft engine operation have been accomplished in developing a "safe" fuel that will not explode in its stored condition when exposed to a spark, but which will give identical engine performance when used in place of fuels being burned today. The Bell air cushion vehicle engine, a General Electric LM100, was tested on the latest emulsified "safe" JP-4 fuel (WSX-7165). Engine starts and operation were about the same with emulsified JP-4 fuel as with plain JP-4 except that running time was limited on emulsified fuel because of fuel nozzle clogging. Clogging was caused by dirtier-than-normal fuel and by an iron deposit that formed on the fuel nozzles and fuel nozzle screens.

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LIST OF SYMBOLS

AD	Alloy depletion
CDP-(P ₃)	Compressor discharge pressure, psi
C/S	Cross section
GO	General oxidation
IGO	Intergrannular oxidation
L/E	Leading edge
mg/gal	Milligrams per gallon
N _f	Free power turbine speed, rpm
N _g	Gas generator speed, rpm
PPH	Pounds per hour
psia	Pounds per square inch absolute
psig	Pounds per square inch gage
TFC	Thermal fatigue crack
T ₂	Compressor inlet temperature, °F
T ₅	Power turbine inlet temperature, °F
T ₆	Power turbine downstream temperature, °F
W _f	Weight flow, fuel

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INTRODUCTION

TEST OBJECTIVE

The objective of the test was to determine the feasibility of burning emulsified fuel in a General Electric LM100 gas turbine. Starting, acceleration, and steady-state characteristics of the engine were compared on liquid JP-4 and emulsified JP-4. The engine was also inspected before and after test to determine what, if any, deleterious effects resulted from burning emulsified fuel.

Emulsified fuel offers several advantages over liquid fuels from a safety viewpoint. Emulsified fuel burns much slower and has a higher open-cup flash point. It has a low rate of vaporization, since it stays in a jelly-like form until sheared through pumps and filters prior to entering the engine combustion chamber.

LM100 ENGINE

The LM100 gas turbine is an industrialized version of the T-58, the major difference being its controls. The engine used for the test was a 7LM100PD101 that had been returned for overhaul. This engine had accumulated 329 hours of service in Vietnam in an air cushion vehicle.

The 7LM100PD101 fuel system consists of a flight (T-58) fuel pump, high-pressure filter, flow divider, and fuel nozzles. An industrial fuel metering valve and stopcock are used. Lube oil is cooled in an oil-to-fuel engine-mounted heat exchanger.

DESCRIPTION OF TEST INSTALLATION

The test stand used a dynamometer that consisted of the compressor portion of an aircraft turbosupercharger to absorb the engine output horsepower. A means of varying the load was provided by a damper valve in the supercharger inlet. Temperature rise across this unit was monitored as an indication of engine performance. Actual engine performance was based on N_g , T_5 , and CDP. Figure 1 shows this test stand.

Fuel was supplied to the engine from a pressurized stainless-steel tank. Initial emulsified fuel testing was done with the standard engine high-pressure fuel filter. After approximately 4 hours of testing, engine fuel manifold pressure started rising with fixed engine conditions. When it was evident that the pressure was not going to stabilize, the engine was shut down and the fuel filter was inspected for contamination. This filter was completely clogged and was in a bypass condition, allowing the fuel nozzles to be unprotected. The fuel nozzles were replaced, and a 46-micron filter was installed close to the fuel pump inlet. Fuel and lube temperatures were also monitored so that the effectiveness of the engine lube-oil-to-fuel heat exchanger could be evaluated. Overspeed and over-temperature protective devices were incorporated in the test installation to shut the engine down automatically in the event that one of these conditions existed.

DISCUSSION

TESTING

Prior to the testing, a hot-section inspection of the engine was performed. Figures 2 through 6 show the results of this inspection. New fuel manifold assemblies and two new first-stage turbine blades were installed. An overhauled fuel metering valve was installed so that corrosion could be monitored. Otherwise, only those parts necessary to run the engine safely were replaced at this time.

The test consisted of making comparisons of starting, acceleration, and steady-state characteristics on JP-4 and WSX-7165 emulsified fuel.

Testing included:

1. Start and acceleration calibration runs on JP-4.
2. Start and acceleration test runs on WSX-7165 emulsified fuel.

Testing of the engine on emulsified fuel was to the following schedule:

1. Operating for 5 minutes at 1200°F T₅.
2. Operating at 1175°F T₅ for 1-1/2 hours.
3. Operating at 1050°F T₅ for 25 minutes.
4. Repeating steps 1, 2, and 3 as fuel supply permitted.

A total of 11 hours 37 minutes running time was accumulated during the test. Of this total, 9 hours 32 minutes was on emulsified fuel.

A flowmeter calibrated on emulsified fuel was not provided for this test. The following method was used to compare engine fuel consumption rate of JP-4 and emulsified fuel:

1. Determine the known operating time on emulsified fuel at each particular condition.
2. Calculate the total amount of JP-4 fuel that would have been used at each condition.

3. Determine the total amount of JP-4 fuel that would have been used for the total running time on emulsified fuel.
4. Compare this total with the actual total amount of emulsified fuel used.

TEST RESULTS

Engine performance on emulsified fuel was identical to that on JP-4 with the exception of light (backfire) explosions. These explosions were heard during starting, transit, and steady-state conditions. Transit and steady-state explosions were audible and accompanied by an irratically indicated T_5 and streaks of flame in the exhaust. These explosions were not numerous and were probably caused by blobs of emulsified fuel burning downstream of the combustor.

After 4 hours 18 minutes (3 hours 17 minutes on emulsified fuel), the fuel manifolds were changed because of high fuel manifold pressure. This was caused by the fuel nozzles' clogging on dirty fuel (see Figures 7, 8, and 9). Bench checks showed five secondary fuel nozzles not flowing at inlet pressures up to 500 psig. All nozzles were dirty and clogged to some extent. Two secondary nozzles had collapsed nozzle filter screens. This is shown in Figures 10 and 11. Also, globs of emulsified fuel were dribbling out of these nozzles, as shown in Figures 13 and 14. A white crystal-like residue was also found (see Figures 15 and 16) on the nozzles. Figures 17, 18, and 19 are typical of the condition of the other fuel nozzles in the first set.

The second set of manifolds was in much better condition at the end of the test. A slave filter had been added to the fuel supply system when the manifolds were changed. These nozzles were about 35 percent clogged at the end of the test. There was some white residue around the nozzle orifices, but there were no blobs of fuel. The nozzles had been operated on JP-4, whereas the first set had been operating on emulsified fuel prior to shutdown. Clogging of the first set of fuel nozzles was caused by contaminated fuel. Figures 21 through 28 show typical fuel nozzles from the second set.

Fuel nozzles from the second set were disassembled, and a reddish deposit was found on the screens and in the nozzle areas. This deposit was inadvertently cleaned from the second set of nozzles prior to obtaining a sample for chemical analysis. However, there was a similar coating in the first set of nozzles in addition to all the other contaminant.

A sample of this reddish deposit was analyzed and found to be primarily iron, with traces of aluminum, calcium, chromium, copper, magnesium, manganese, nickel, lead, silicon, and titanium. Flow check of the second set of nozzles after ultrasonic cleaning restored them to pre-test condition

Laboratory analysis revealed that the fuel contained sand, a large amount of fiber, and large pieces of material that appeared to be gray paint. The contamination level was 17.8 mg/gal. MIL-T-5624G allows 8 mg/gal for liquid JP-4.

Comparison of the fuel consumption of WSX-7165 and the expected fuel flow on liquid JP-4 revealed the fuel flows to be essentially the same. The expected fuel consumption on liquid JP-4 for known engine conditions was 829 pounds. The actual amount of WSX-7165 fuel burned during the comparison was approximately 825 pounds. Data from this test are given in the table.

ESTIMATED FUEL CONSUMPTION		
Power Setting T ₅ (°F)	Running Time (min)	Estimated JP-4 Consumption (lb)
1180	20	205
1170	10	100
1165	10	97.5
1060	7	58
1140	5	45.5
1125	29	295
745 (idle)	12	28

The engine-mounted lube-oil-to-fuel heat exchanger was sufficient for the test. Comparisons showed that the lube oil temperature drop across the heat exchanger was considerably less on emulsified fuel than on liquid JP-4 shown by the data sheets in Appendix II.

Figures 29 through 36 are pictures of the hot-section parts after test. A blue coloring on most of the hot-section parts was analyzed and found to be a cobalt-based material. It is surmised that the cobalt came from hot-section materials, as each component that was coated incorporated a high percentage of cobalt. The coloring did not show on the second-stage

nozzle or on the power turbine buckets. The second-stage nozzle material is 713 (B50T1239), and the power turbine buckets are A286. The blue-colored coating did not adhere to these two metals. See Appendix VIII.

Analysis of the first-stage buckets from pre-test to post-test condition showed no apparent change as a result of emulsified fuel operation. The one bucket that had experienced 300 hours of Vietnam operation plus the emulsified fuel test was in the same general condition as the two that were analyzed prior to this test. The new coated bucket installed prior to the test showed the coating to be in good condition at post-test time, with general oxidation estimated at 0.5 to 1.0 percent. Also, the coated bucket showed a trace of alloy depletion, but nothing was found in the analysis of the coated or uncoated bucket that could be identified as being of a destructive nature caused by operation with emulsified fuel.

PROBLEMS

Fuel Nozzles

Fuel nozzle coking may be a problem in achieving required nozzle life if emulsified fuel is supplied to the fuel nozzles. The primary fuel nozzles were coked the heaviest. This suggests that spray characteristics with emulsified fuel are much poorer at lower pressure drops across the fuel nozzles. The secondary nozzles, which operate only above 185-psi fuel manifold pressure, showed much less coking. Coking was aggravated by dirty fuel's clogging the nozzles.

Since emulsified fuel must be pumped to move, it will not drain after shutdown but will stay in the nozzle and coke. Secondary fuel nozzles showed signs of this, since they do not flow below 185-psi manifold pressure. Figures 18 and 19 show coking on the secondary nozzles which can be attributed to high-temperature no-flow conditions.

Fuel Drains

Emulsified fuel will not flow through the engine drains. If a start is aborted or the engine fails to light off, fuel could accumulate in the combustor. Then, if a second start is initiated and the engine lights, this accumulation of fuel might also ignite and a dangerous overtemperature condition could exist.

Backfires

The backfire-type explosions with simultaneous streaks of flame in the exhaust were probably caused by the fuel's not burning in the combustor. If emulsified fuel is supplied to the fuel nozzle, a redesign will be required. Redesign of the fuel system to de-emulsify the fuel completely before it reaches the nozzles may be more attractive.

It is suspected that a change in T_5 profile occurred as a result of fuel nozzle clogging. No damage resulted from this suspected change, nor was there any sign of deterioration of hot-section parts. This assumption is based on variations of the T_5 - T_6/N_g - T_5 relationships and on a rise in fuel manifold pressure as a function of time.

Contamination

Emulsified fuel will pick up and hold all impurities that it comes in contact with. These impurities must be filtered out. The fuel system must therefore be kept very clean or designed to be compatible with the contamination. Testing had to be suspended to change clogged fuel filters.

CONCLUSIONS

Based on the results of this test, the following conclusions are drawn:

1. The LM100 engine and fuel control system used in conjunction with the Bell air cushion vehicle are capable of short-duration operation using WSX-7165 emulsified fuel.
2. Engine starting on emulsified fuel creates no problems, and fuel consumption rate is very close to that of JP-4 under the same steady-state conditions.
3. Although no lube temperature problems were encountered in this test, lube temperature drop across the oil cooler indicated that emulsified fuel will not be as efficient a cooling medium as liquid JP-4.
4. The LM100 fuel system will experience no adverse corrosion problems from short-duration operation on WSX-7165 emulsified fuel under average conditions.
5. The LM100 engine and fuel system would require extensive tests, such as fuel nozzle and component combustion tests, and probably design changes in some areas before they could be released for operation on WSX-7165 emulsified fuel for extended periods.

RECOMMENDATIONS

1. Since the results of this test indicate satisfactory short-duration (4 to 6 hours) operation for the LM100 engine and fuel system supplied by the General Electric Company, it is recommended that a similar test be conducted on an engine installed in an air cushion vehicle to determine the feasibility of operation in conjunction with the craft fuel system that is presently in use with standard JP fuels. This test would dictate the changes necessary in the total system and could be a prelude to any tests that might be conducted in aircraft applications.
2. An LM100 component combustor test is recommended to determine flame pattern and differences in combustor operation between straight JP-4 fuel and WSX-7165 emulsified fuel. Combustor operation should also be compared using new fuel nozzles versus nozzles that have operated from 4 to 6 hours and experienced the 35 to 40 percent restriction noted with the second set of nozzles used in this test.
3. Experiments and tests are recommended to determine the feasibility of developing a cleaning fluid that might be injected periodically into the fuel system to clean fuel nozzles of the deposits that cause clogging with extended operation on WSX-7165 emulsified fuel.
4. It is recommended that methods to de-emulsify the fuel completely, prior to injection into the fuel nozzle manifolds, be investigated. This would certainly preclude the backfires, would stop blobs of emulsified fuel from being spewed into the combustion section, and would eliminate the engine drain problem. It appears that the fuel must be completely de-emulsified by the time that it reaches the fuel nozzles; otherwise, a redesign will be required.
5. A test on a new LM100 engine with a new, clean fuel system operated with clean emulsified fuel is recommended. This would eliminate the uncertainty that presently exists as to why and where the contamination and blue-colored coating came from on the engine that has just completed testing.
6. It is recommended that hot-section materials be tested to determine what deleterious effects (i. e. , alloy depletion, oxidation, etc.) result from burning emulsified fuel.

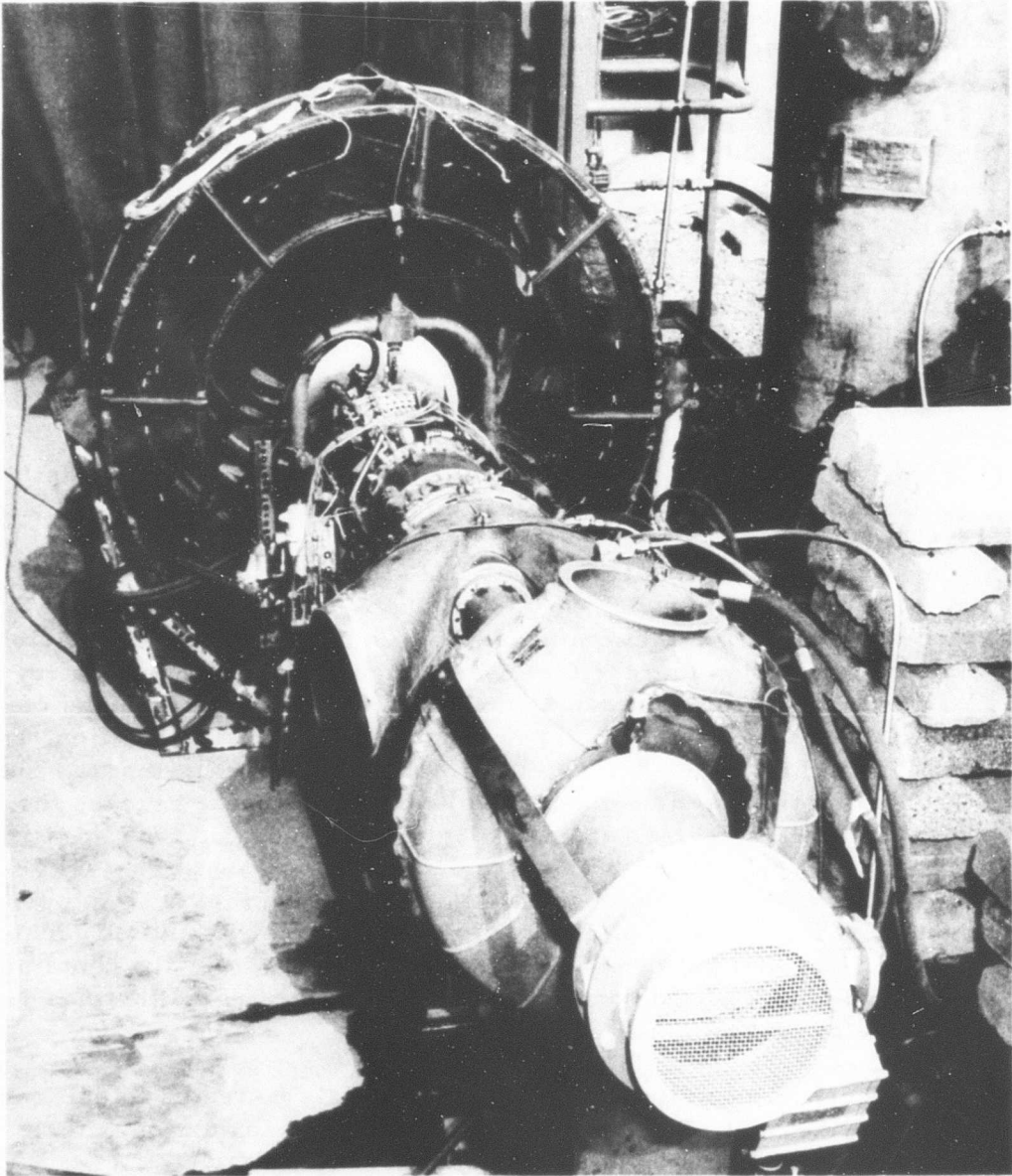


Figure 1. Test Stand.

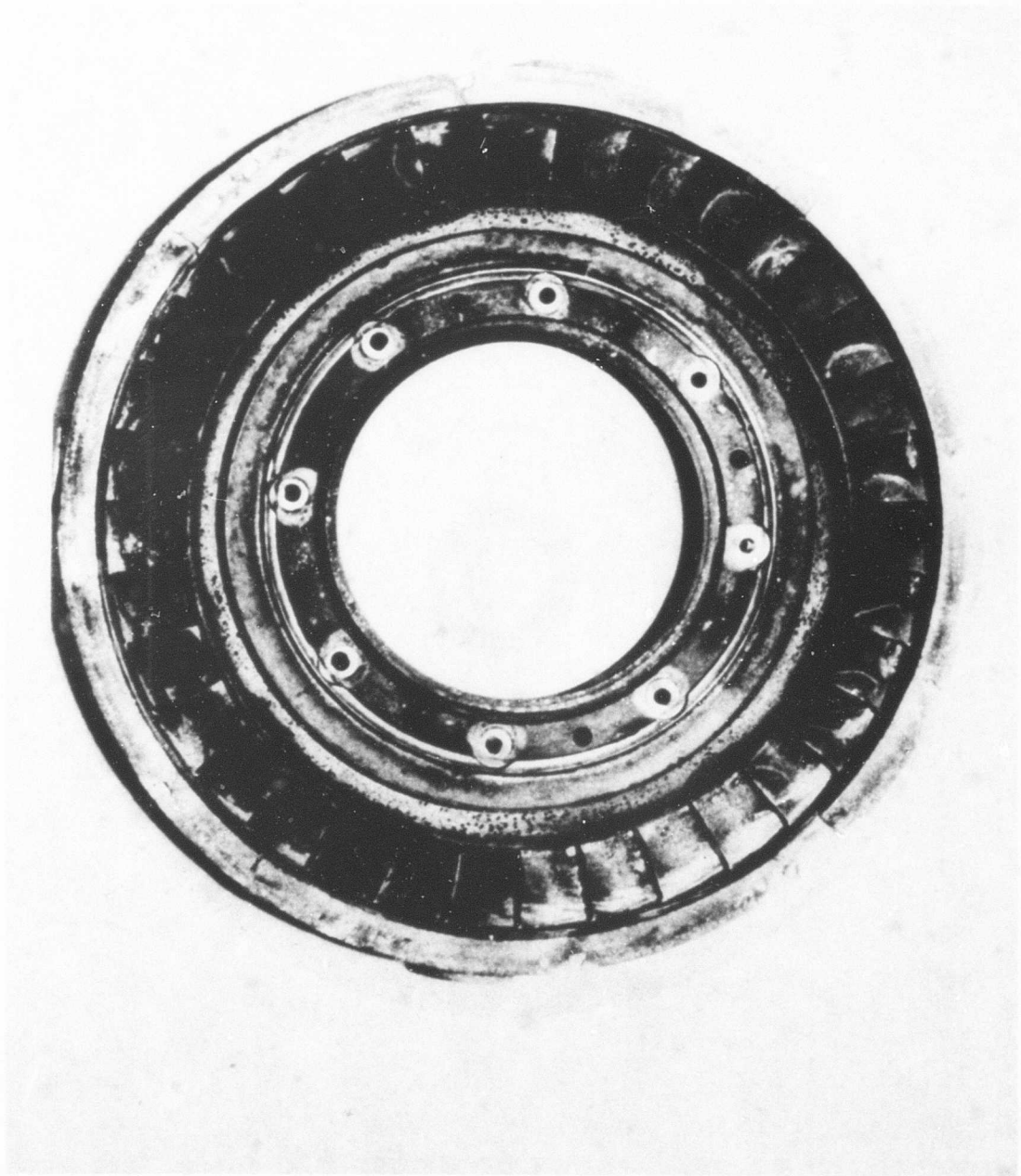


Figure 2. First-Stage Nozzle, Pre-Test Condition.

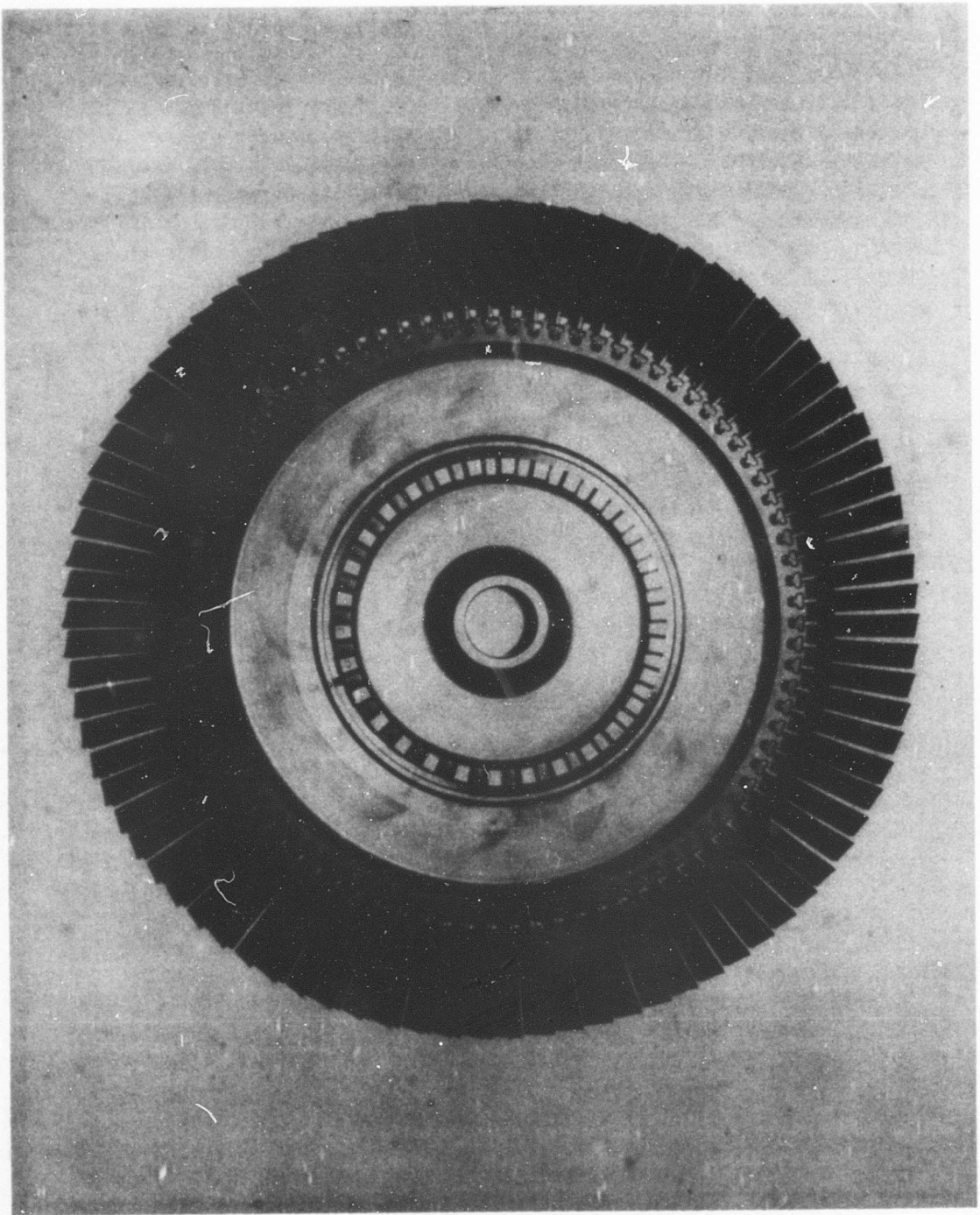


Figure 3. First-Stage Turbine Wheel, Pre-Test Condition.

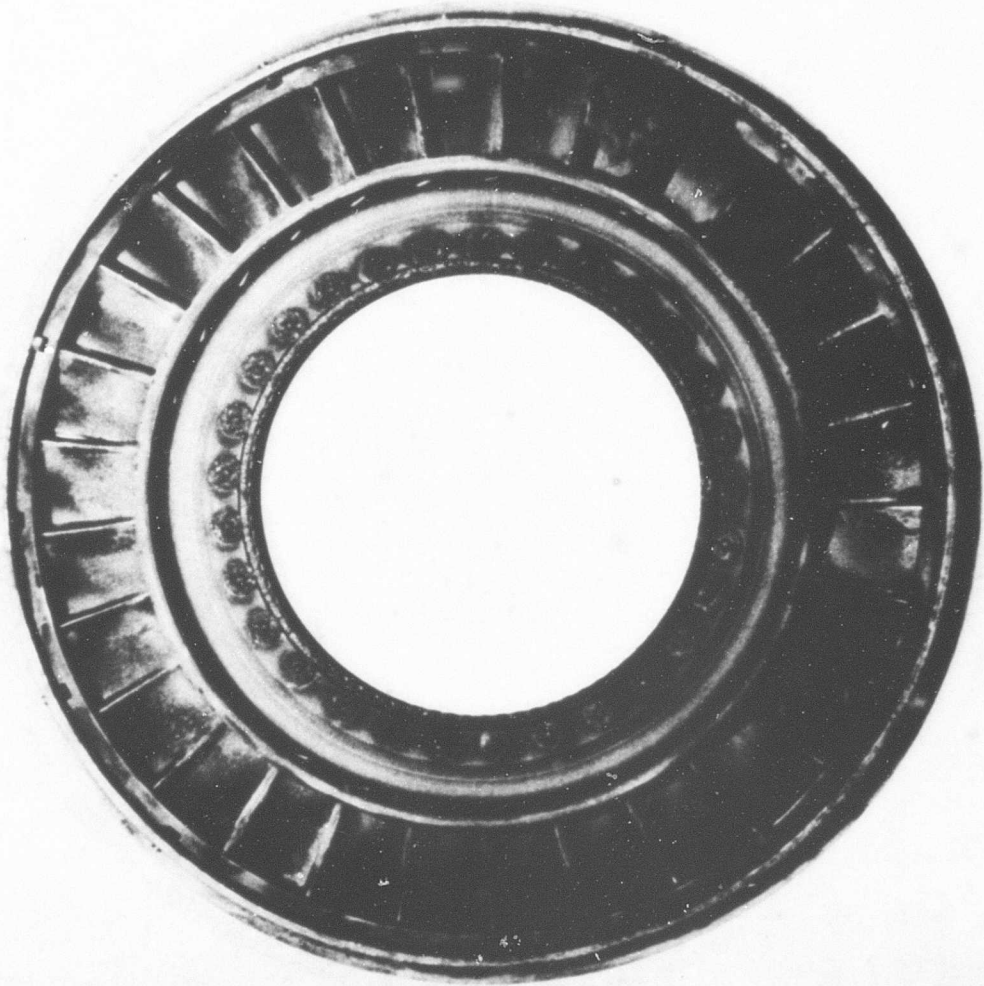


Figure 4. Second-Stage Nozzle Before Test, Leading Edge.

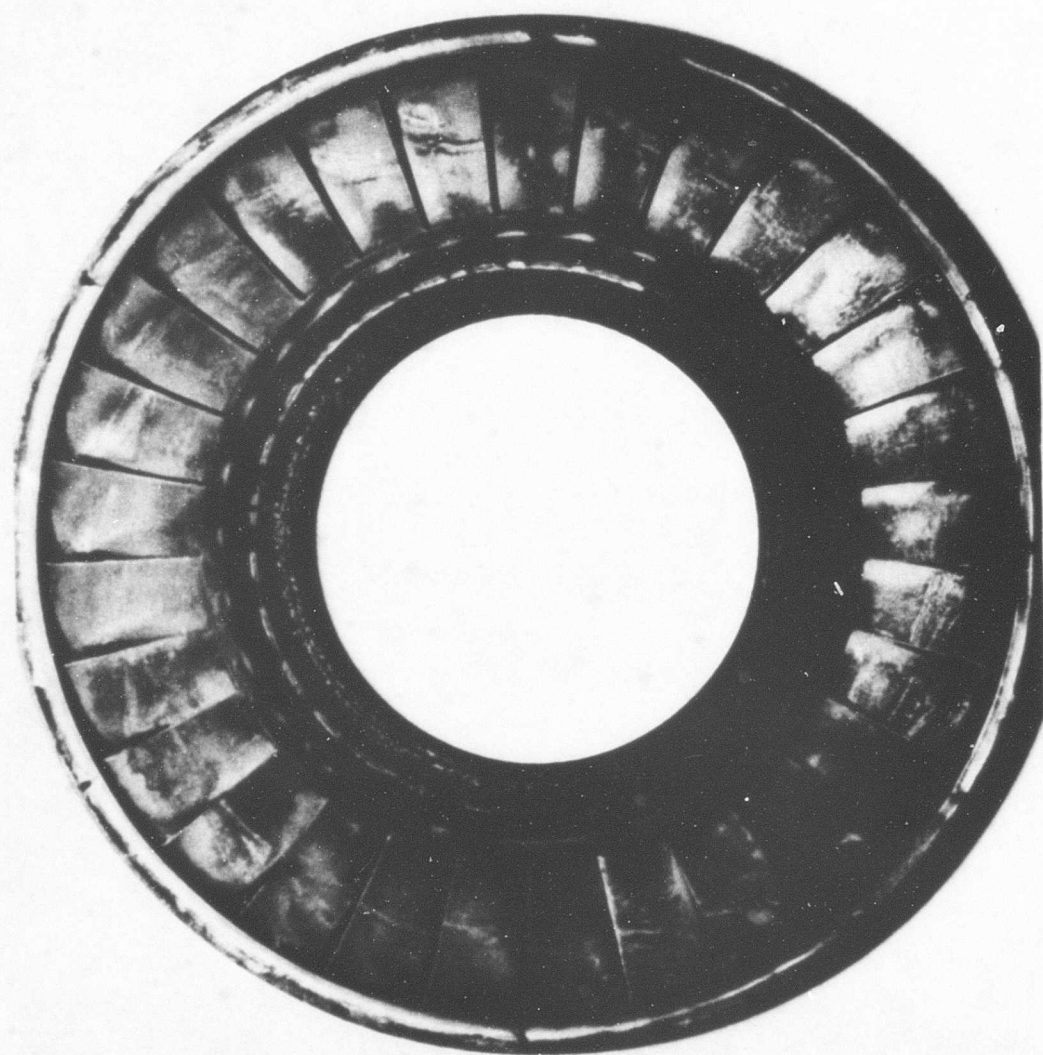


Figure 5. Second-Stage Nozzle Before Test, Trailing Edge.

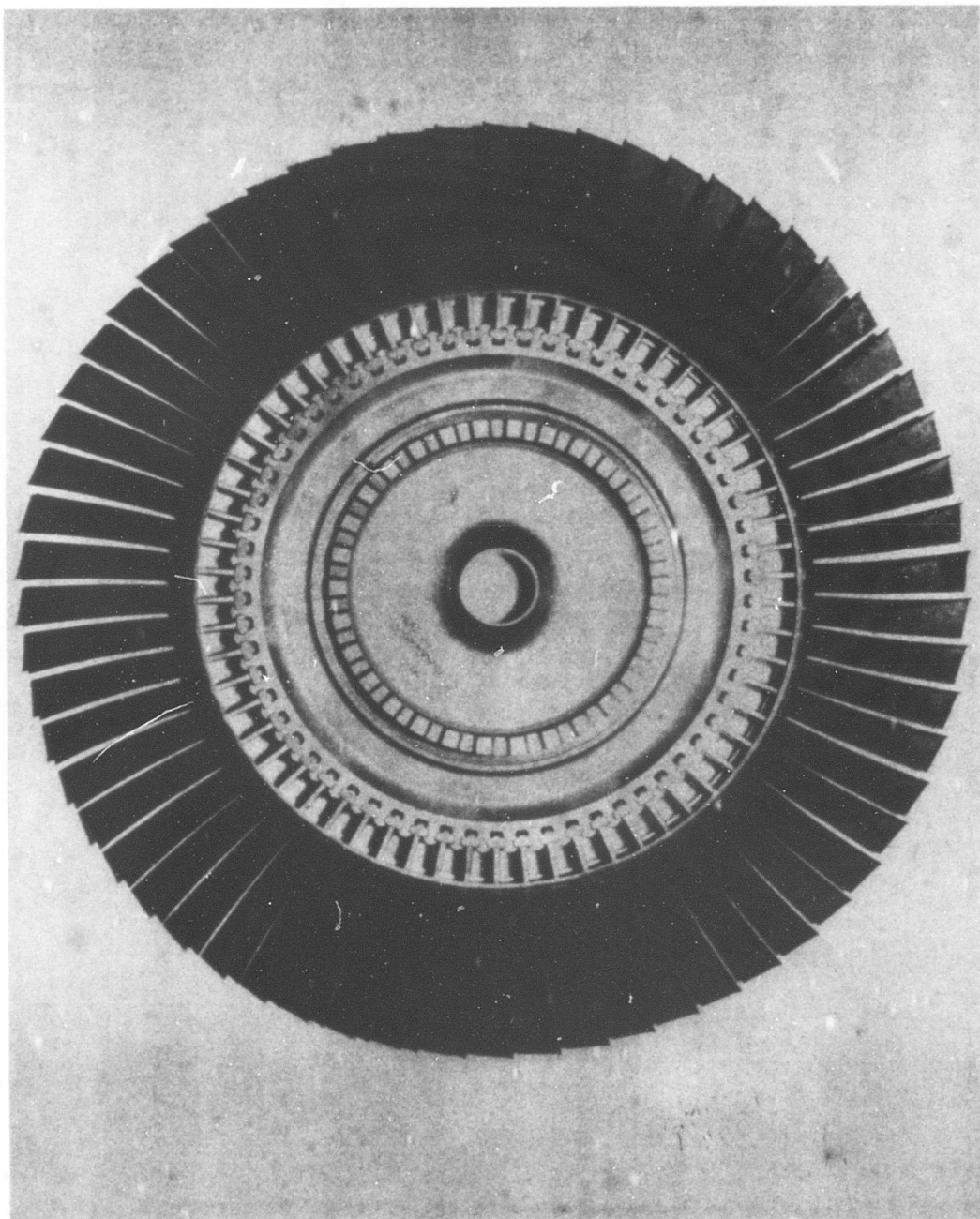


Figure 6. Second-Stage Turbine Wheel, Pre-Test Condition.



Figure 7. Clogged Secondary Fuel Nozzle (Upstream View).



Figure 8. Clogged Primary Fuel Nozzle (Upstream View).

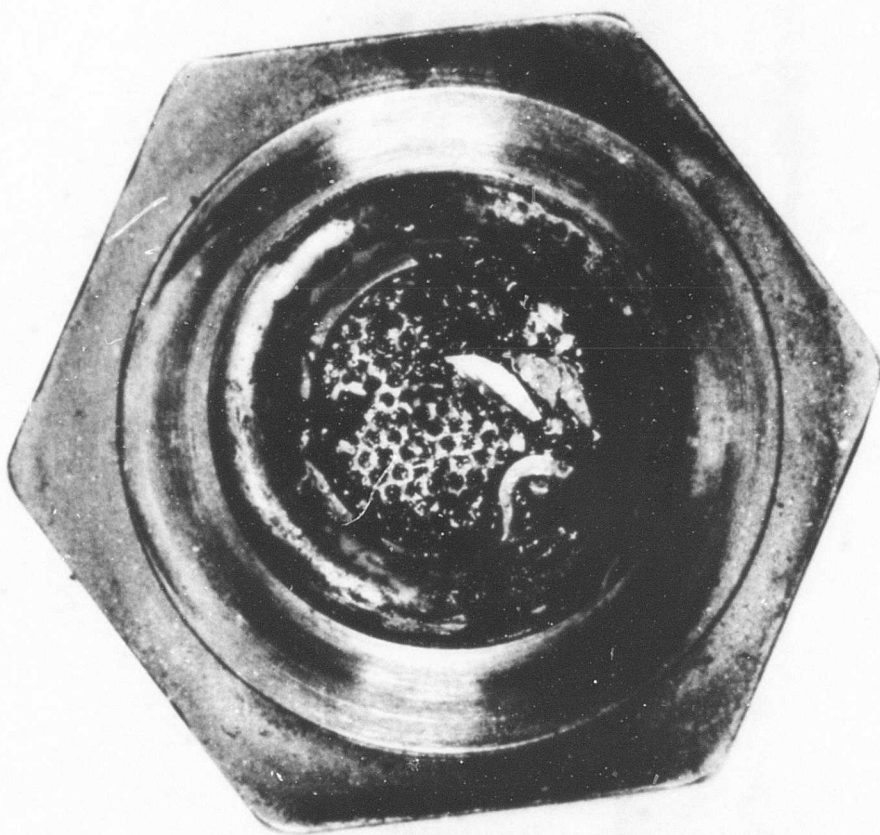


Figure 9. Clogged Primary Fuel Nozzle (Upstream View).

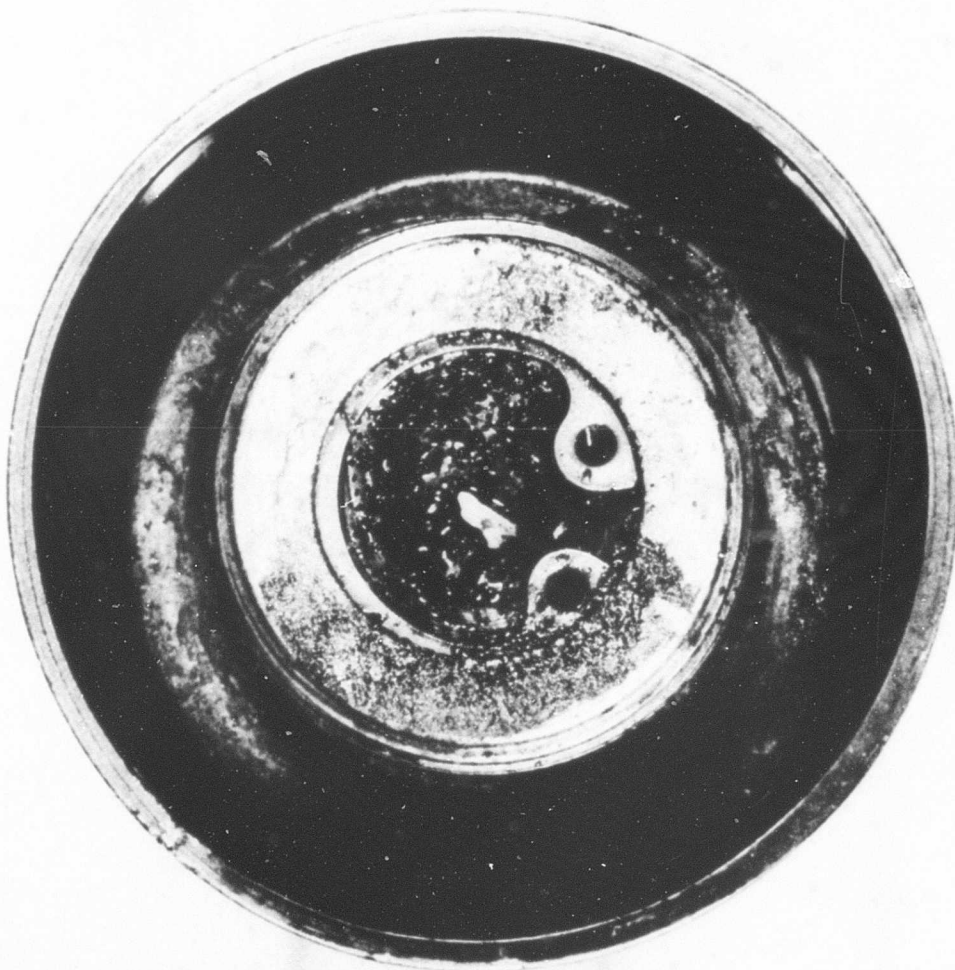


Figure 10. Clogged Secondary Fuel Nozzle With Collapsed Filter Screen (Upstream View).

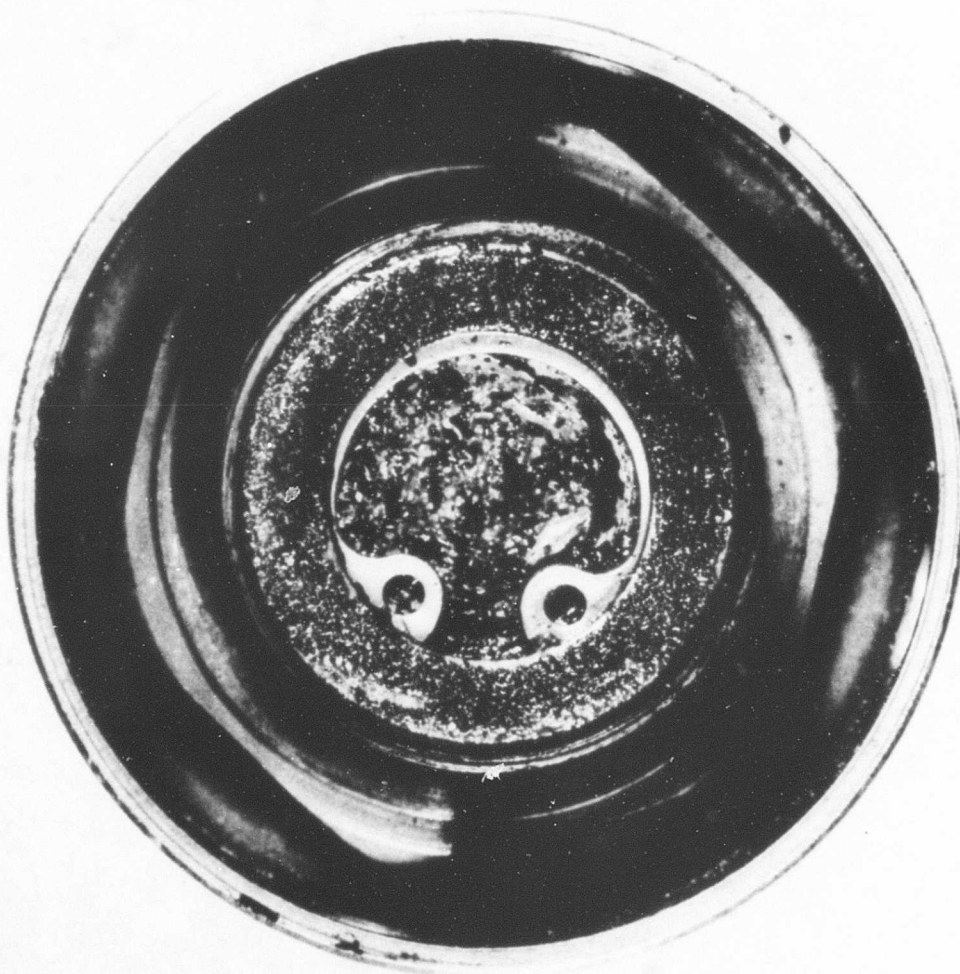


Figure 11. Clogged Secondary Fuel Nozzle With Collapsed Filter Screen (Upstream View).

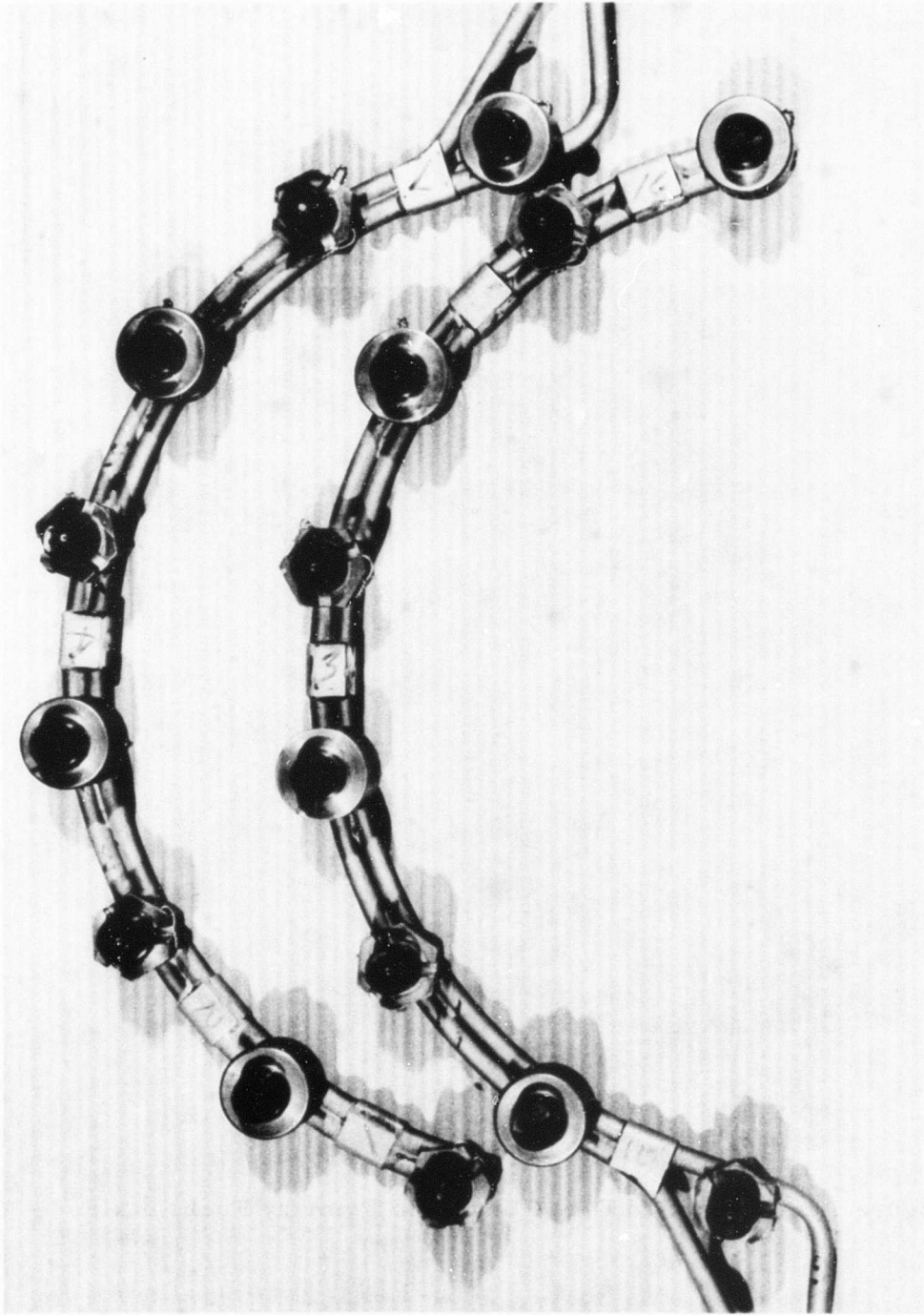


Figure 12. First Set of Fuel Nozzles.

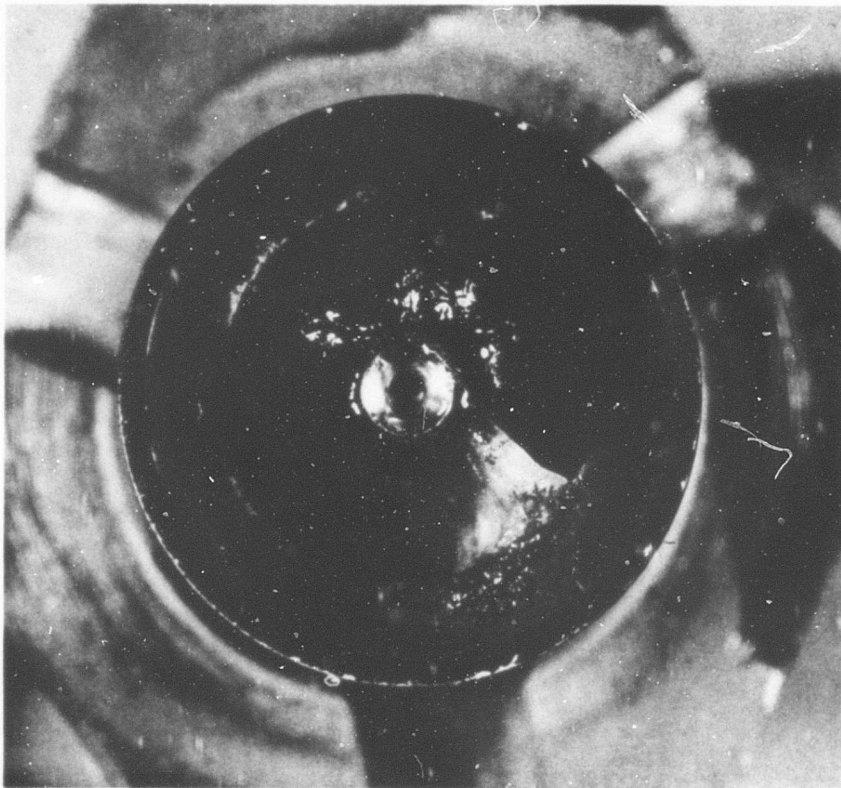


Figure 13. Emulsified Fuel Clinging to Primary Fuel Nozzle.

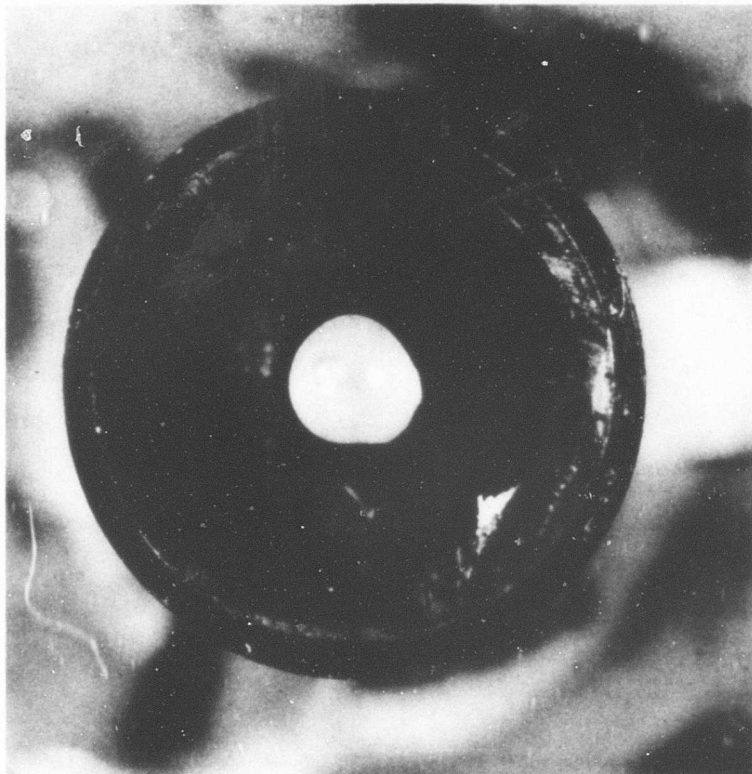


Figure 14. Emulsified Fuel on Primary Fuel Nozzle After Shutdown.

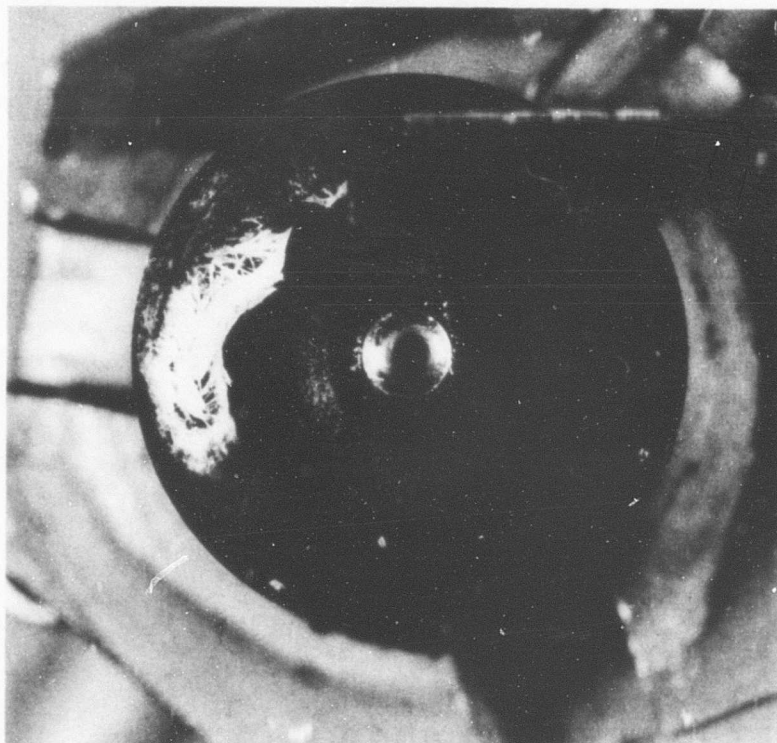


Figure 15. White Residue Found on Fuel Nozzles.

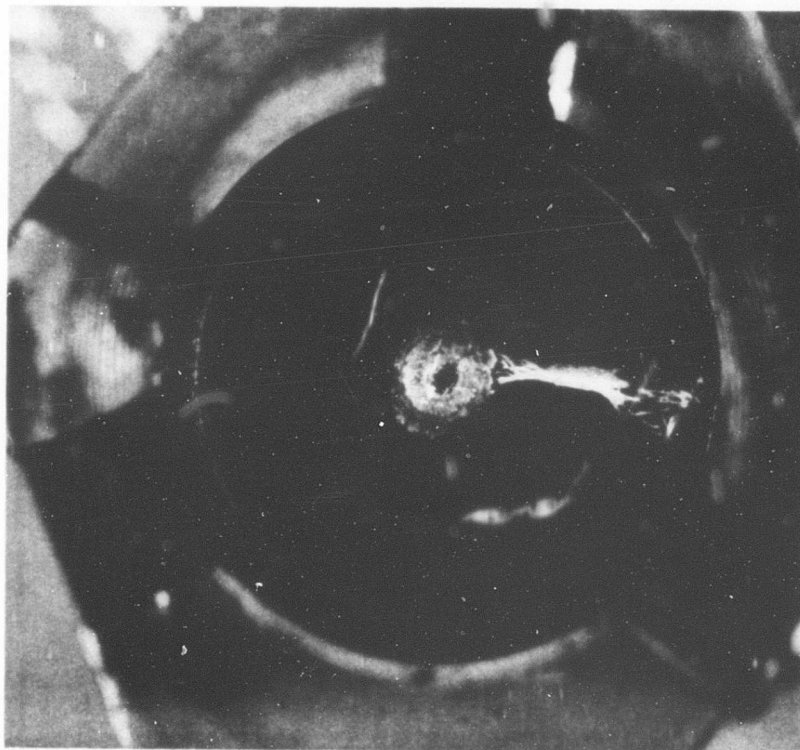


Figure 16. White Residue Found on Fuel Nozzles.

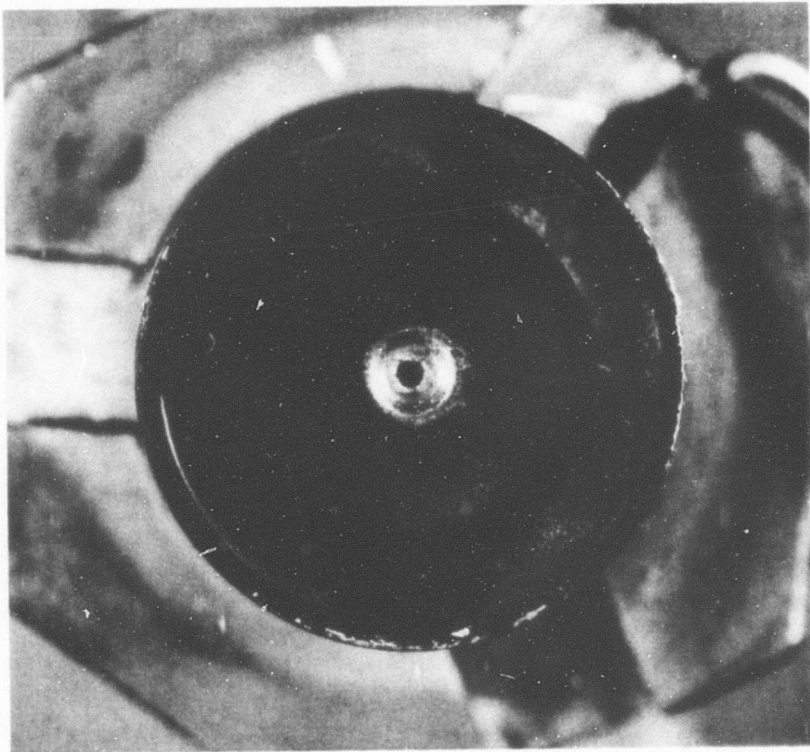


Figure 17. Primary Fuel Nozzle Coking.

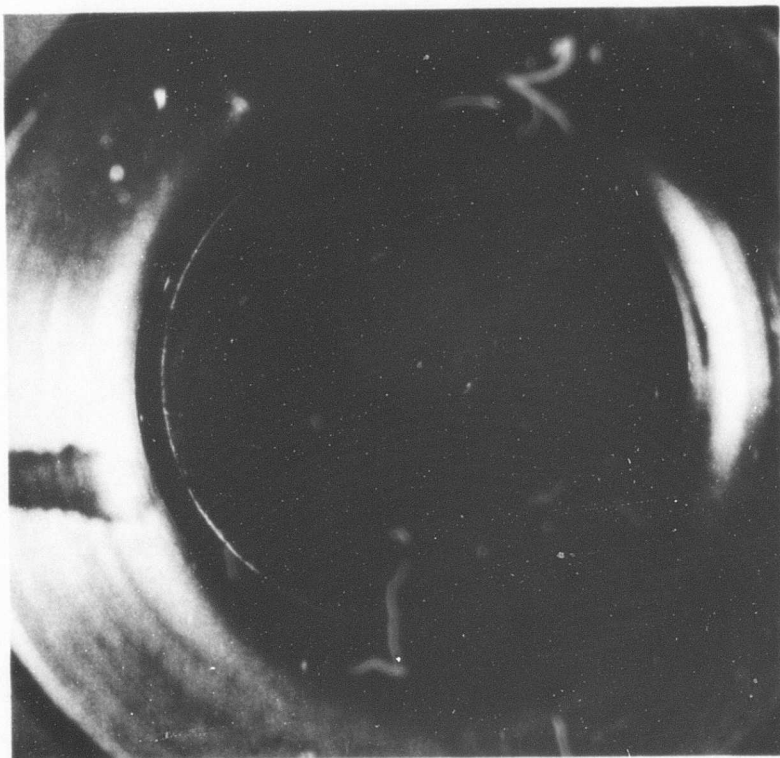


Figure 18. Secondary Fuel Nozzle Coking.

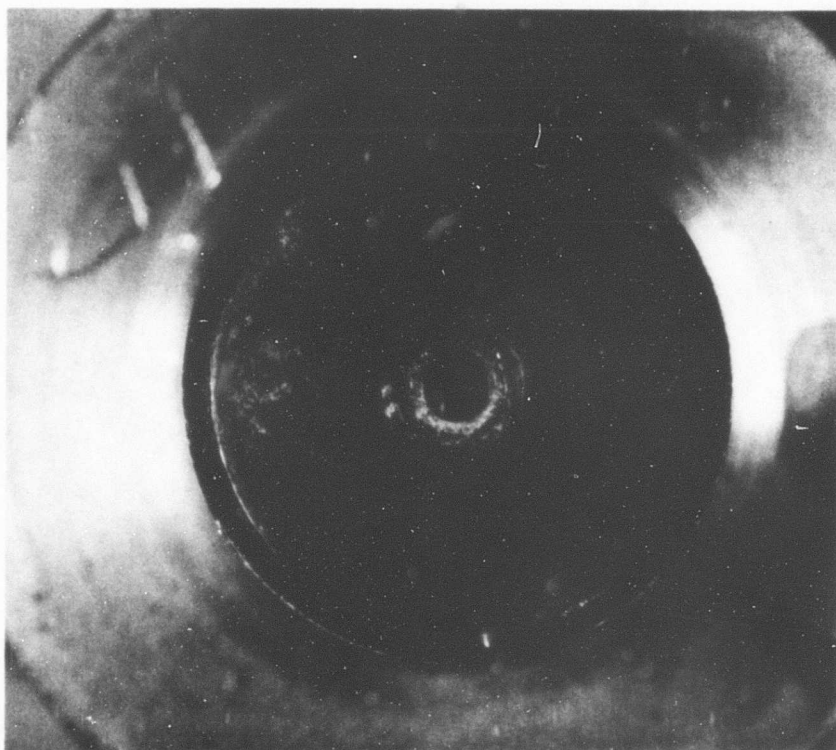


Figure 19. Secondary Fuel Nozzle Coking.

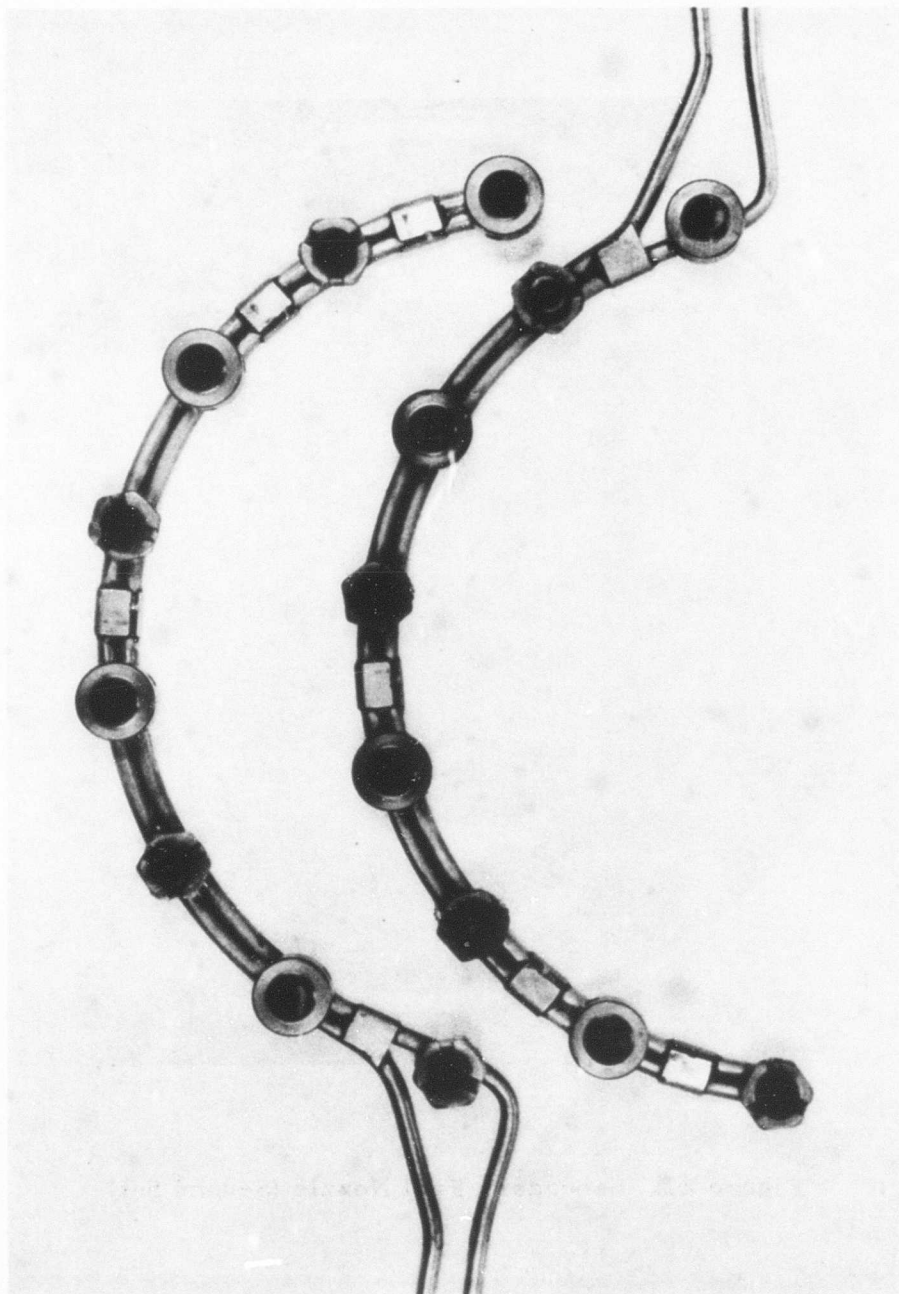


Figure 20. Secondary Set of Fuel Nozzles After Test.

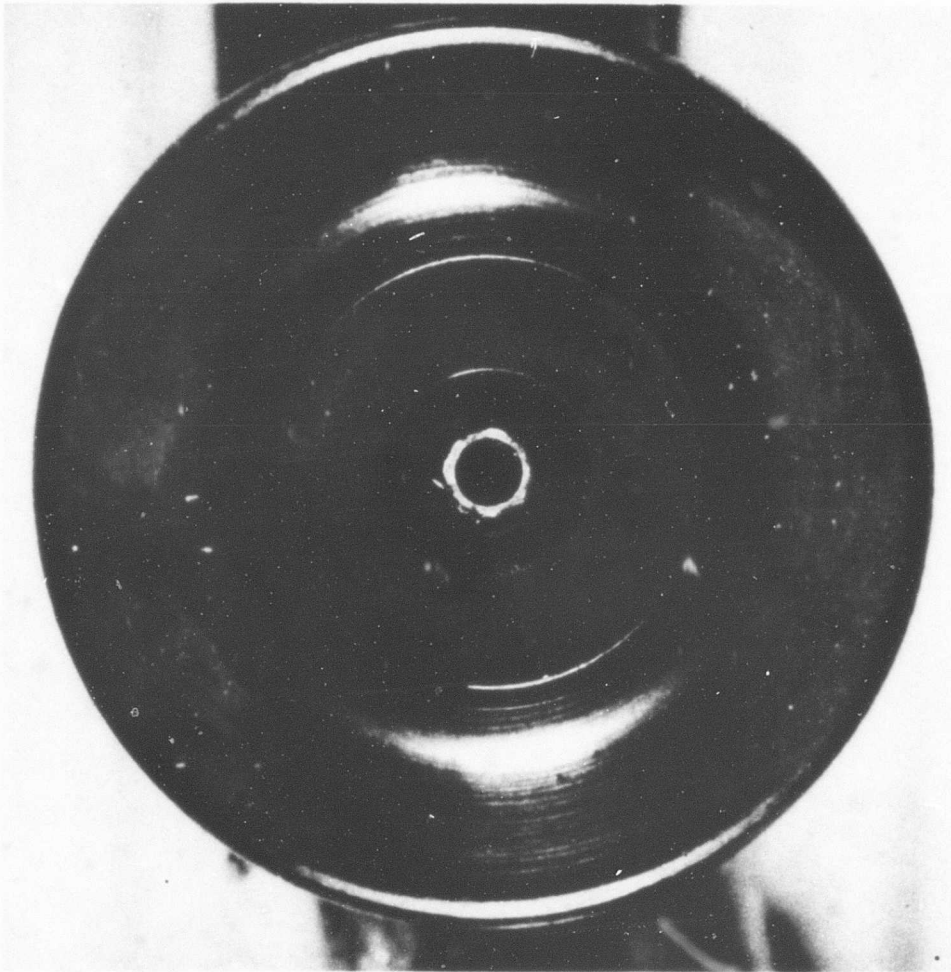


Figure 21. Secondary Fuel Nozzle (Second Set).

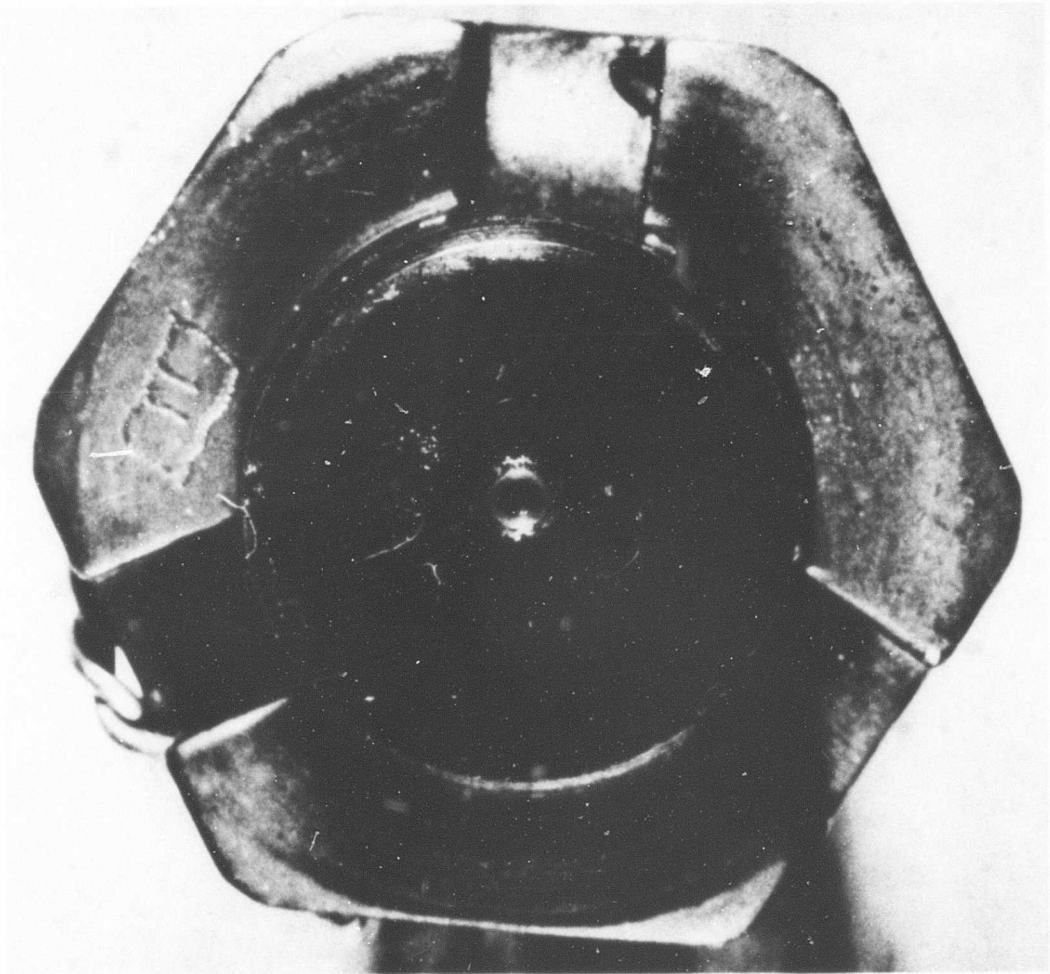


Figure 22. Primary Fuel Nozzle (Second Set).

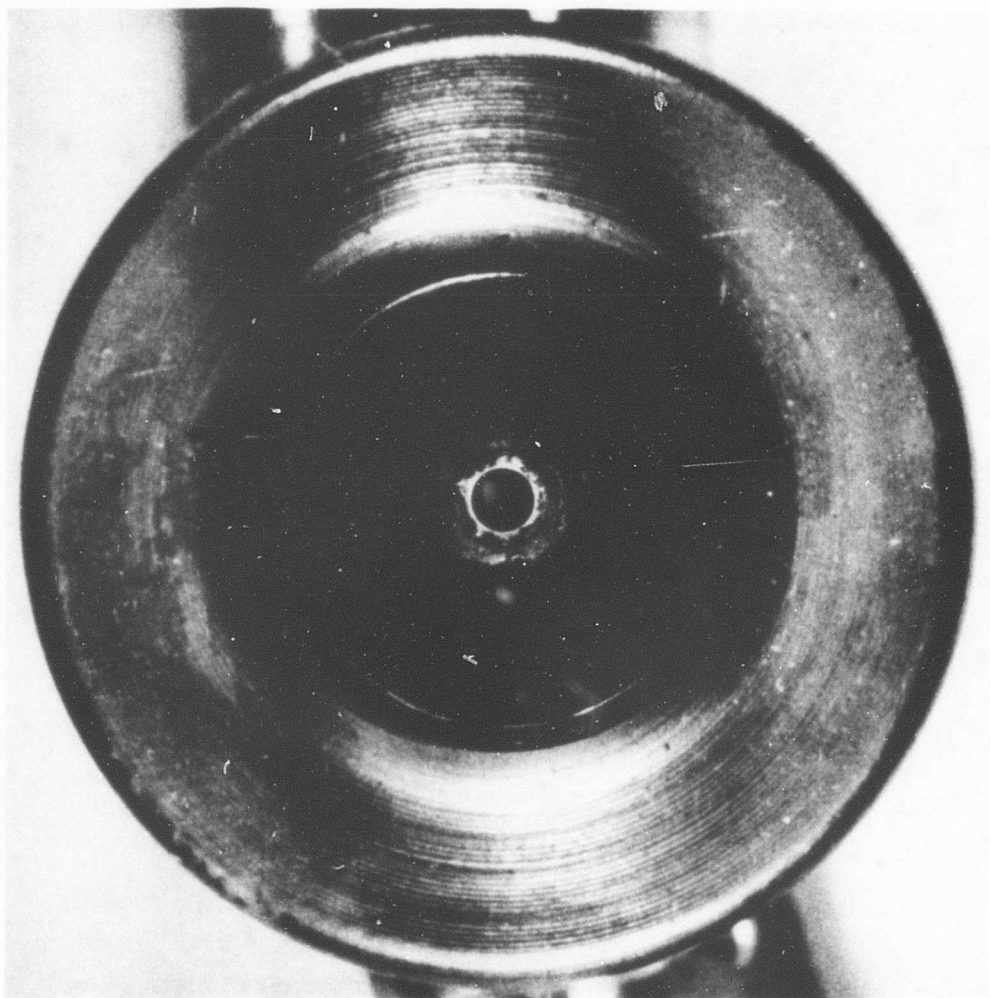


Figure 23. Secondary Fuel Nozzle (Second Set).

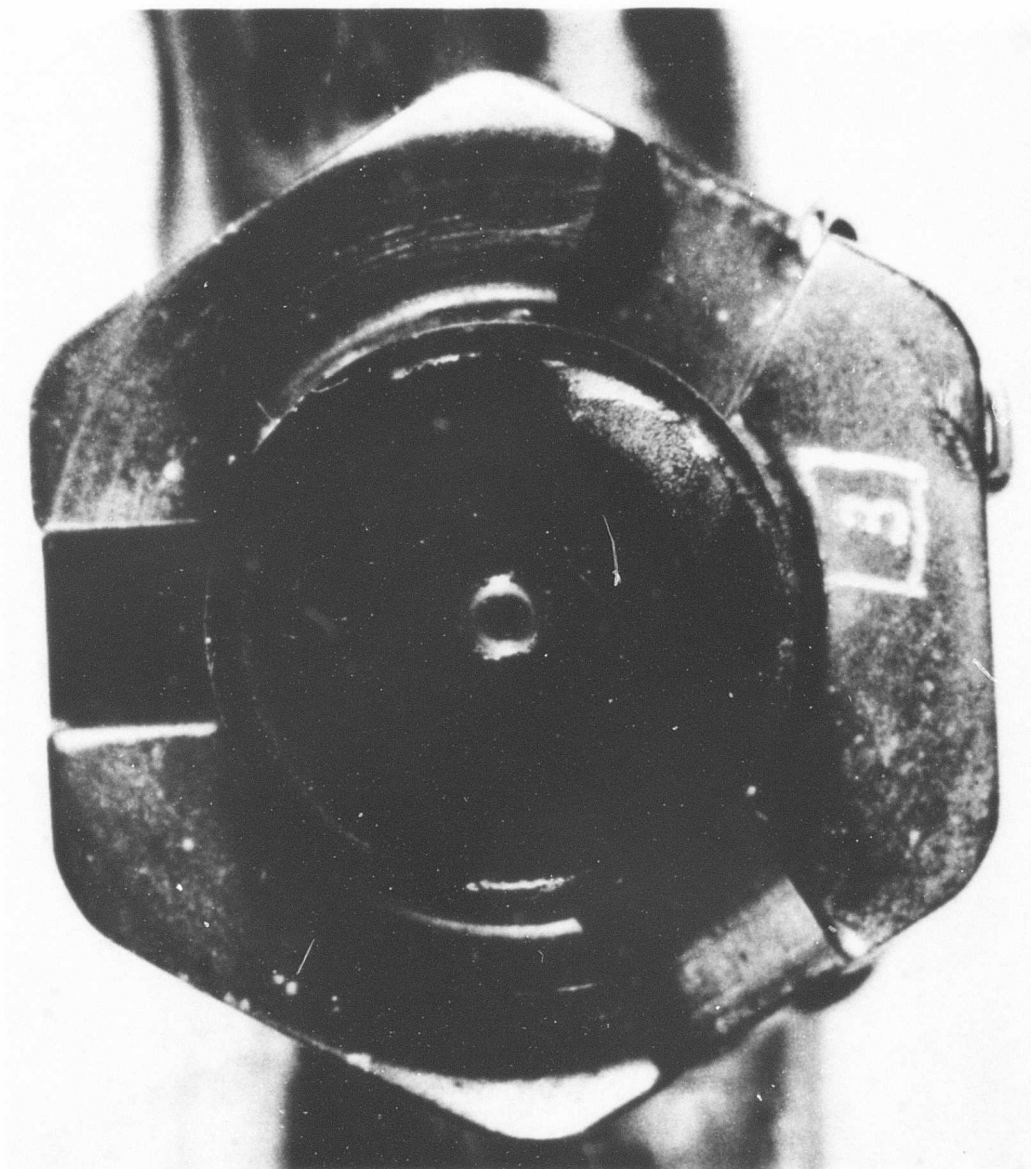


Figure 24. Primary Fuel Nozzle (Second Set).

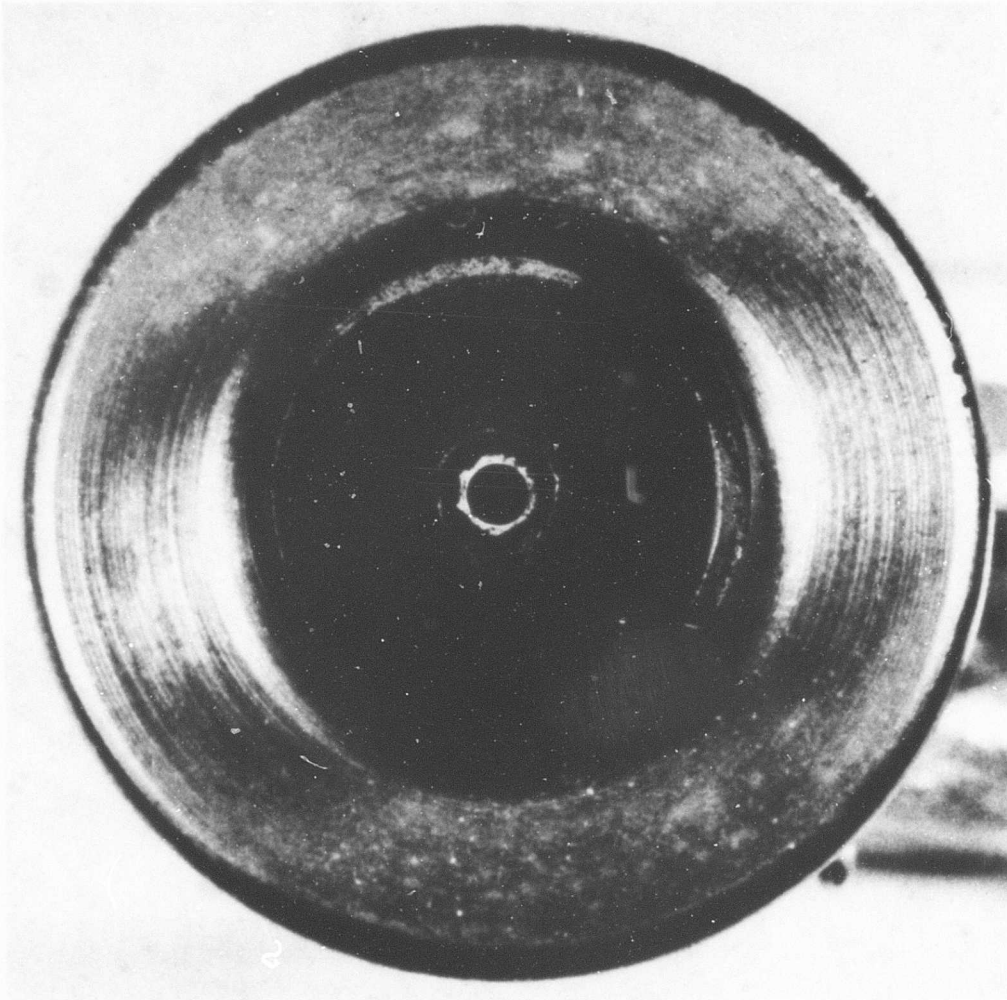


Figure 25. Secondary Fuel Nozzle (Second Set).

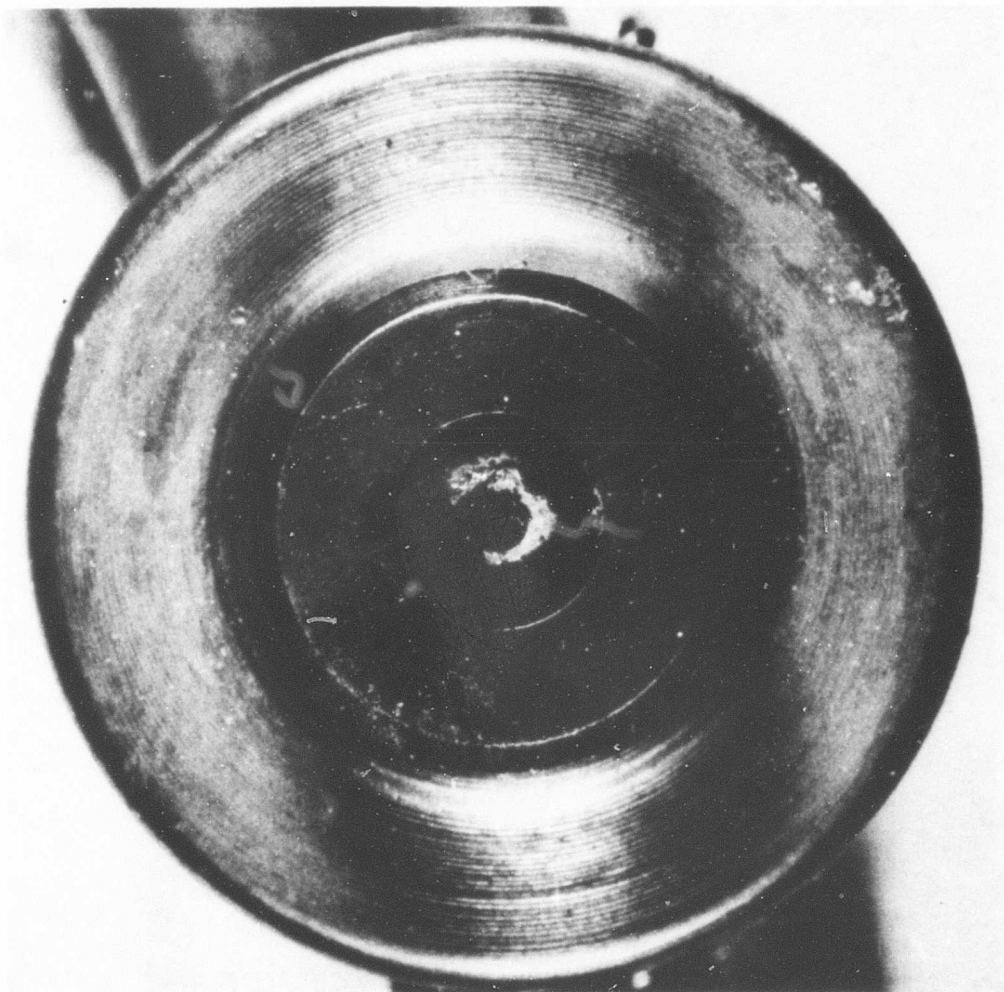


Figure 26. Secondary Fuel Nozzle (Second Set).

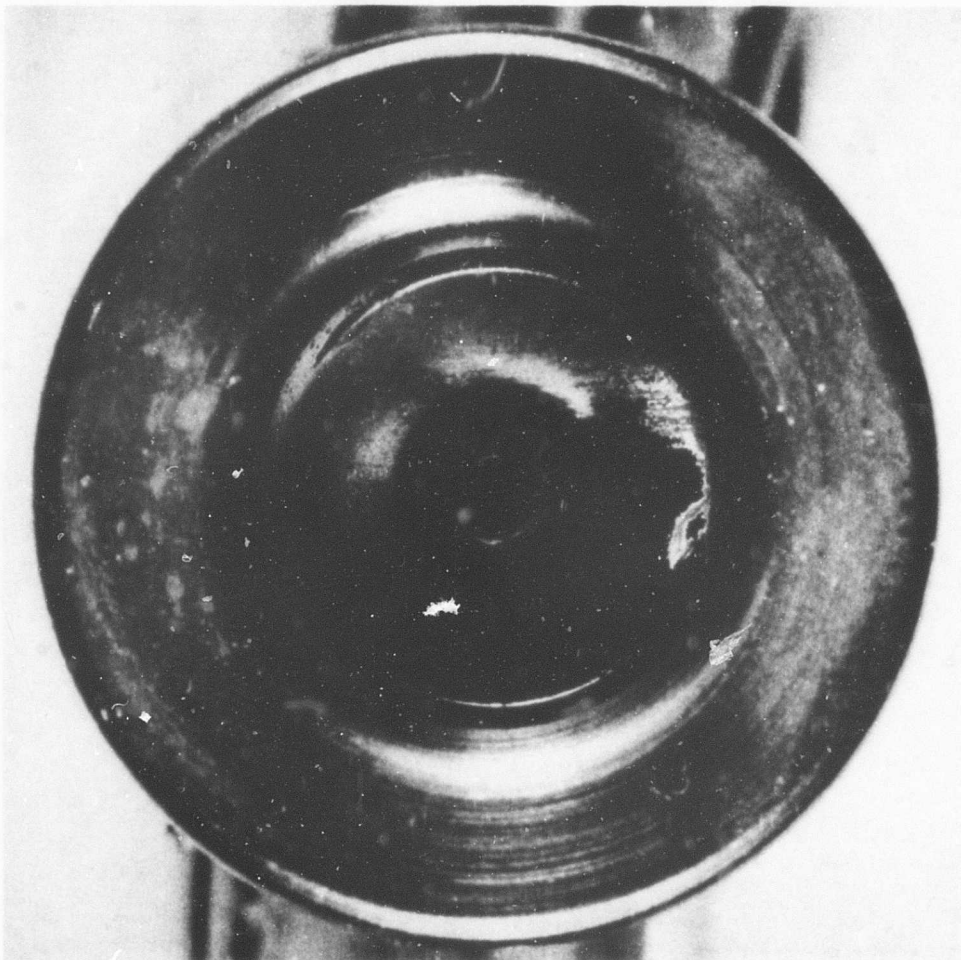


Figure 27. Secondary Fuel Nozzle (Second Set).

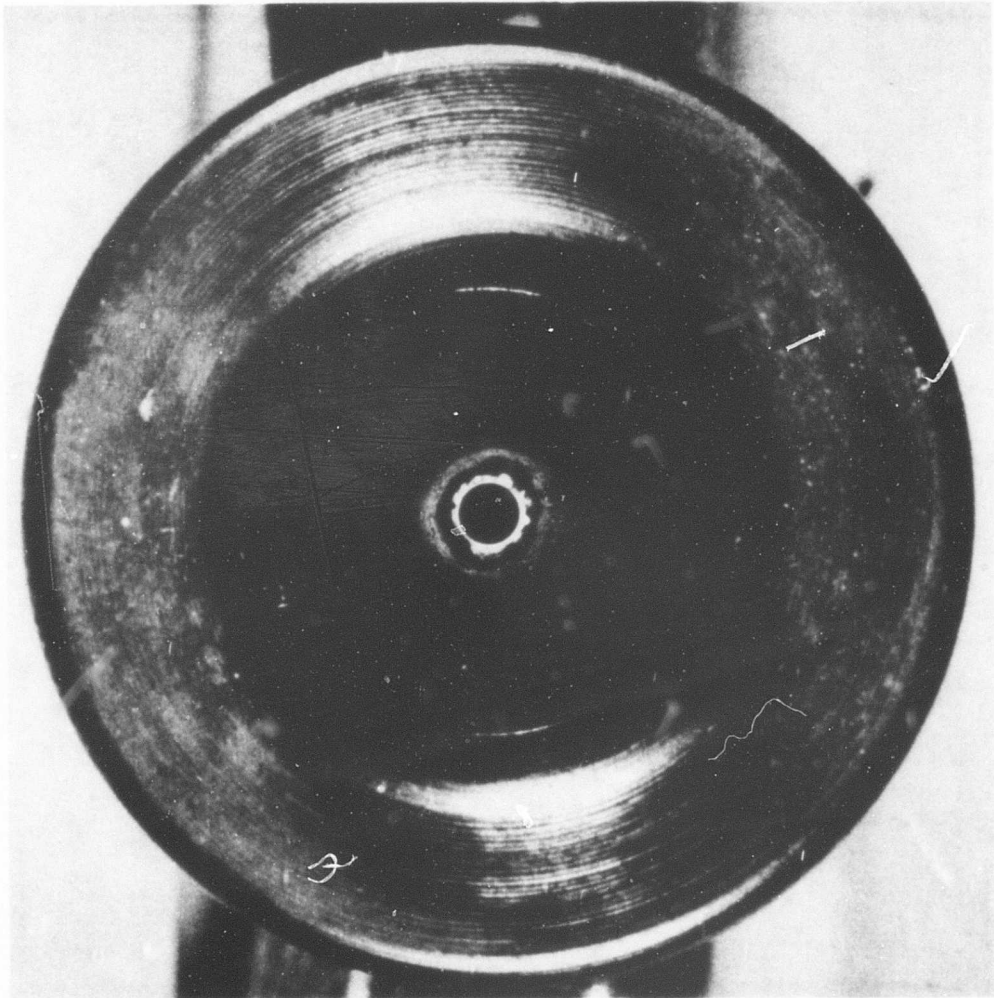


Figure 28. Secondary Fuel Nozzle (Second Set).



Figure 29. First-Stage Nozzle, Leading Edge,
Post-Test Condition.



Figure 30. First-Stage Nozzle, Trailing Edge,
Post-Test Condition.

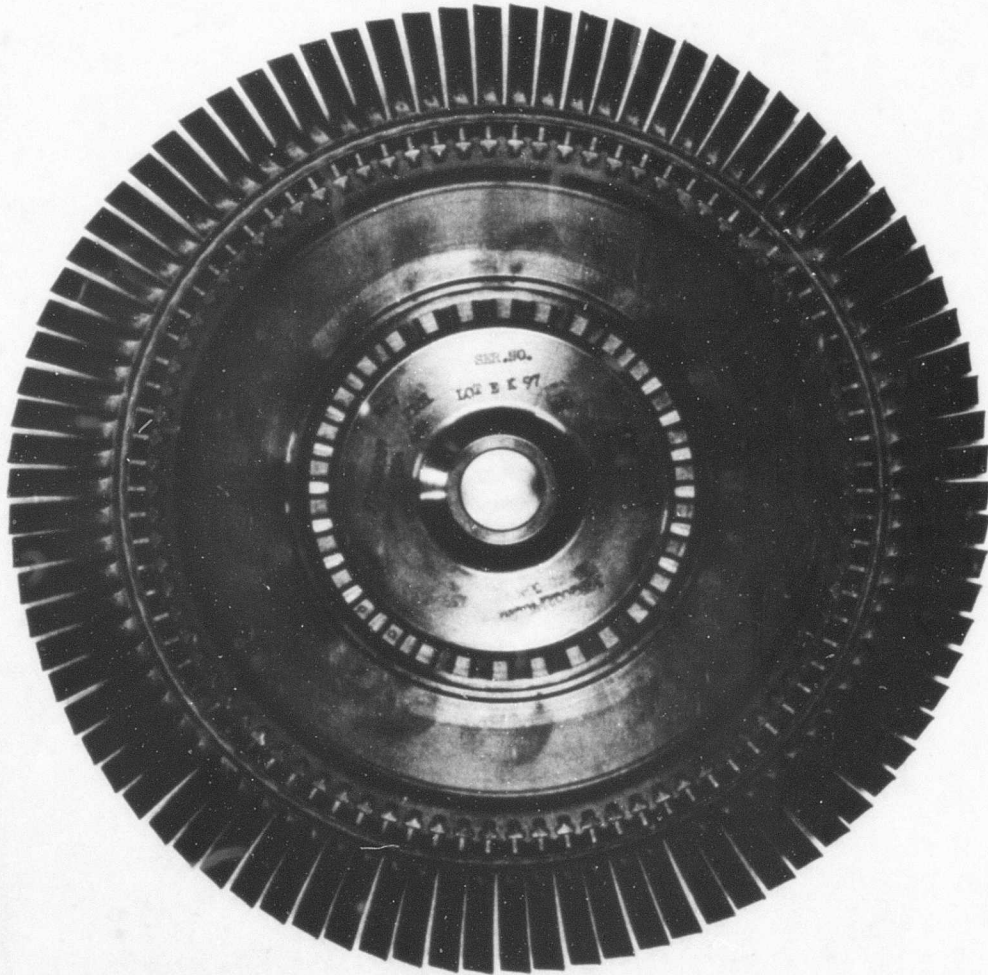


Figure 31. First-Stage Turbine Wheel,
Post-Test Condition.



Figure 32. Second-Stage Nozzle, Leading Edge, and Second-Stage Shrouds, Post-Test Condition.

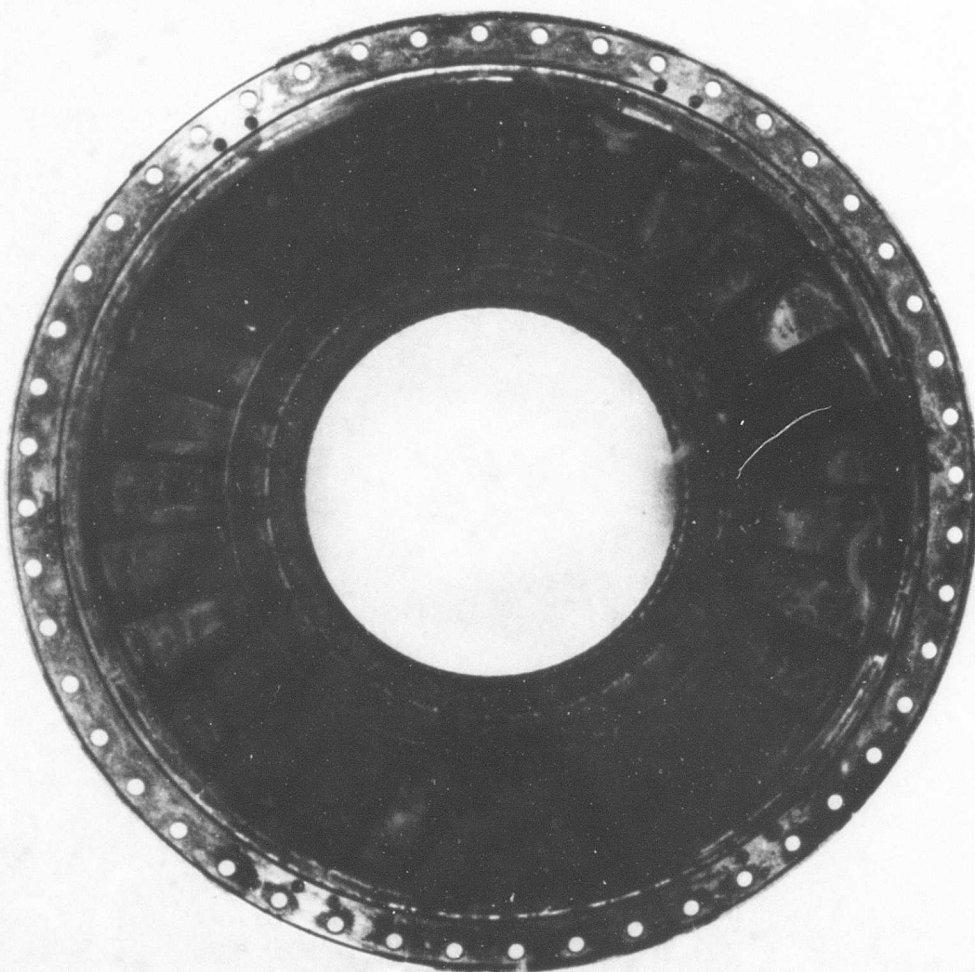


Figure 33. Second-Stage Nozzle, Trailing Edge,
Post-Test Condition.

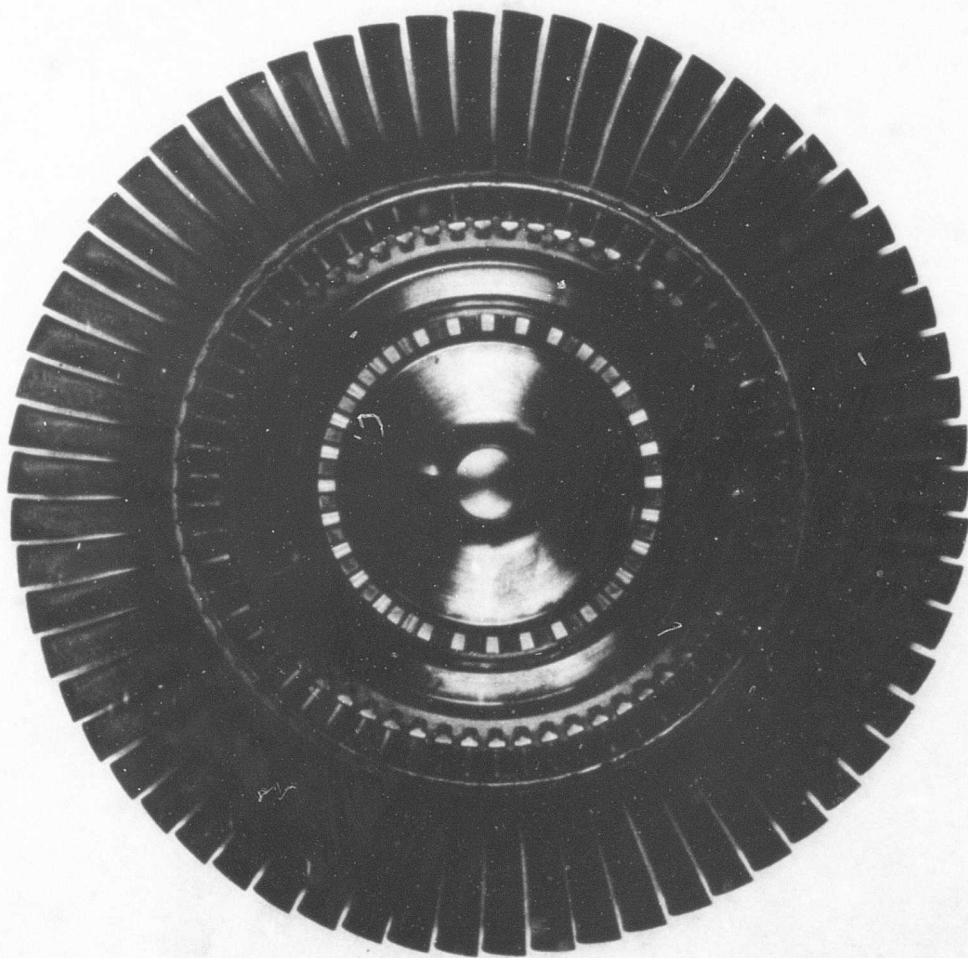


Figure 34. Second-Stage Turbine Wheel,
Post-Test Condition.

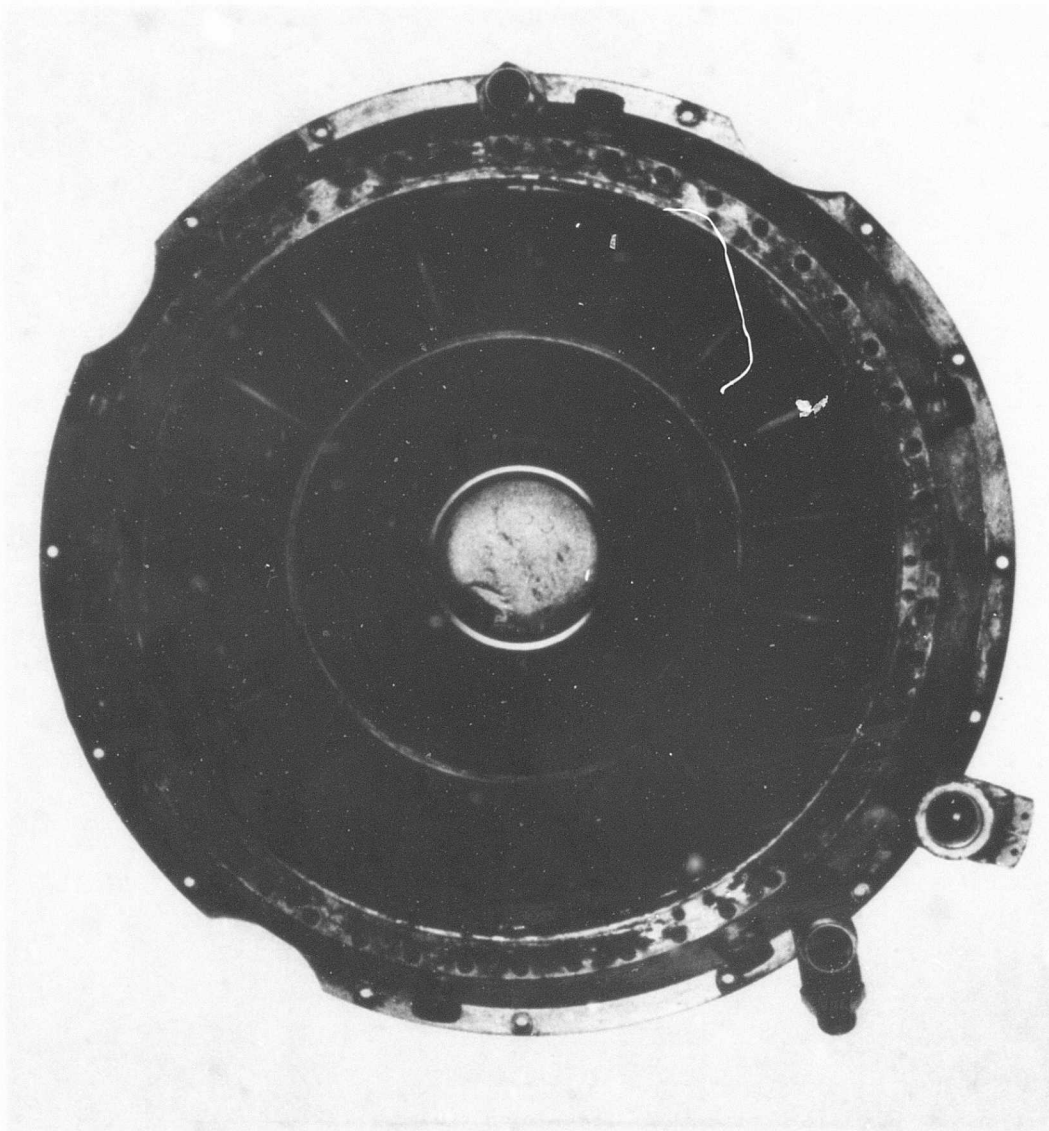


Figure 35. Third-Stage Nozzle Leading Edge,
Post-Test Condition.

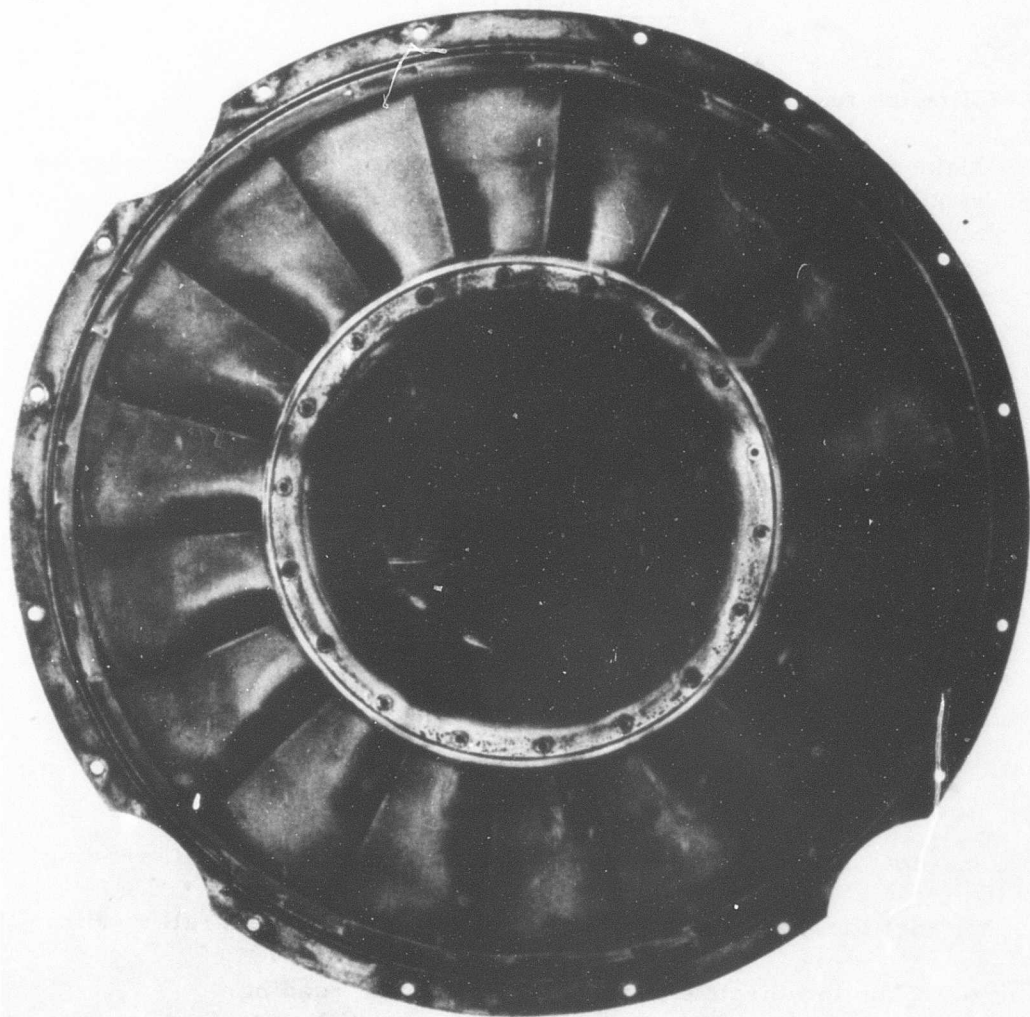


Figure 36. Third-Stage Nozzle, Trailing Edge,
Post-Test Condition.

APPENDIX I

TEST SCHEDULE

The following testing was performed:

1. Make a start under engineering supervision on JP-4 and make any required adjustments. Make three to five starts to assure consistent starting time and T_5 readings.
2. Set $975^\circ - 1000^\circ\text{F}$ T_5 and record T_5 , N_g , N_f , and T_2 . Limit throttle movement so that it cannot be moved beyond the T_5 point. Chop to idle and throttle burst to this point three times. Measure acceleration time with a stop watch.
3. Set T_5 at 1175°F and record T_5 , N_g , and T_2 (reduce T_5 so as to limit N_f to 19,500 if necessary). Limit throttle burst to this point three times. Measure acceleration time with a stop watch.
4. Perform the following tests:
 - a. Adjust the throttle to obtain $T_5 = 1175^\circ\text{F}$, $N_f = 19,500$ and take a full reading.
 - b. Adjust the throttle to obtain $T_5 = 1200^\circ\text{F}$; do not exceed 21,000 N_f or 26,300 N_g . Take a full reading.
 - c. Set the throttle to obtain $T_5 = 1125^\circ\text{F}$ and take a full reading.
 - d. Set the throttle to obtain $T_5 = 1050^\circ\text{F}$ and take a full reading.
 - e. Chop the throttle to idle and take a full reading.
5. Shut the engine down and switch to emulsified fuel.
6. Disconnect the fuel supply line from the engine fuel filter to the flow divider end and place it so that fuel will be collected in a container.
7. Disconnect the inlet to the engine fuel pump and operate the emulsified fuel boost pump until nonaerated fuel is present; then reconnect the line.

8. Open the stopcock and crank the engine until emulsified fuel flows from the flow divider inlet line or until over 1 gallon of fuel has been collected. (Caution: observe starter limitations.)
9. Reconnect the flow divider inlet line and make an engine start on emulsified fuel. Power turbine inlet temperature readings may dictate a change in fuel flow adjustments for starting on emulsified fuel.
10. Repeat step 1 on emulsified fuel.
11. Check gas generator speed versus T_2 and power turbine inlet temperature to assure that tuning is consistent with that set in step 1. Note any differences on the log sheet.
12. Repeat steps 3 and 4 using emulsified fuel.
13. Repeat the following cycle until a total of 6 hours of operation has been completed:
 - a. Operate for 5 minutes at a power turbine inlet temperature of 1200°F or with power turbine maximum speed at 21,000 rpm, whichever is reached first.
 - b. Operate for 1-1/2 hours at a power turbine inlet temperature of 1175°F .
 - c. Operate for 25 minutes at a power turbine inlet temperature of 1050°F .
14. Repeat steps 1, 2, and 3.
15. Repeat step 4 using emulsified fuel.
16. Shut the engine down and switch to JP-4 fuel.
17. Start the engine and operate for 30 minutes at a power turbine inlet temperature of 1175°F or with $N_f = 19,500$ rpm.
18. Repeat steps 1 and 4.
19. Remove the engine from the test cell and flush with JP-4 all facilities that were exposed to emulsified fuel.

TEST LOG SHEETS

[illegible]

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COMPONENT, CONTROLS & ACCESSORIES									
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APPENDIX III
PRE-TEST HOT-SECTION INSPECTION,
ENGINE S/N 125, TURBINE SECTION

STATOR

1. First-stage nozzle - All partitions corroded; 14 cracked on trailing edge.
2. Second-stage nozzle - Five partitions cracked on leading edge (3 o'clock position); badly discolored; shows signs of hot corrosion.
3. Third-stage nozzle - Coking on aft face; visually good.
4. First-stage casing - One dump tube pad has a bolt seized and broken off; internal cooling tubes plugged; otherwise, visually good.
5. Second-stage casing - Visually good.

ROTOR

1. Forward shaft - Visually good; normal discoloration.
2. Cooling plates - Some corrosion; extensive discoloration; not visually warped or otherwise damaged.
3. First-stage wheel - Some evidence of hot corrosion on buckets.
4. Second-stage wheel assembly - Some evidence of hot corrosion.
5. Coupling shaft - Visually good.
6. Tie bolt - Good.

APPENDIX IV
INSPECTION REPORT ON EMULSIFIED FUEL TEST
MANIFOLD ASSEMBLIES, ENGINE S/N 125

BACKGROUND

Running time: 4 hours 18 minutes

Time on JP-4: 1 hour 1 minute

Time on emulsified fuel: 3 hours 17 minutes

These manifold assemblies were removed from the engine because of suspected clogging indicated by high fuel manifold pressure.

VISUAL INSPECTION

White crystal-like deposits were found on four primary nozzles. Coking was evident on primary and secondary nozzles. The coking was apparently caused by dribbling. The primary nozzles were coked the heaviest. Globbs of fuel were hanging on two primary nozzles.

The nozzle strainer completely clogged in two secondary nozzles. All strainers were dirty. Contamination appeared to be chips of paint, sand, and wood (same type of contamination found in fuel filter).

FLOW CHECK

Five secondary nozzles clogged at 500 psig. All others were dribbling heavily.

APPENDIX V
POST-TEST HOT-SECTION INSPECTION OF
EMULSIFIED FUEL, ENGINE S/N 125

Test time: 11 hours 37 minutes

Time on emulsified fuel: 9 hours 37 minutes

- 1. First-stage nozzle - Leading edge oxidized; blue deposit on part exposed to primary air; some white salt-like deposits; does not appear to have deteriorated during test.**
- 2. Second-stage nozzle - Brownish deposit on trailing edge; no blue deposit; otherwise, same as pre-test.**
- 3. Third-stage nozzle - Blue color; otherwise, no change in appearance.**
- 4. First-stage buckets - Heavy blue deposit covering both sides.**
- 5. Second-stage buckets - Heavy blue deposit.**
- 6. Third-stage buckets - White salt-like deposits; otherwise, no change.**
- 7. Cooling plates 1 and 2 - White deposits on cooling air side.**
- 8. Combustion liner - Some carbon deposits close to fuel nozzle; essentially as before test.**
- 9. Fuel manifolds - Coking on all nozzles; primaries coked the most; much better than first set; no globs of emulsified fuel seen.**
- 10. Fuel control valve S/N 704043 - Some small globs of emulsified fuel still present; no signs of corrosion or scale.**
- 11. Flow divider S/N CGW 1842 - Emulsified fuel clinging to springs; a black (varnish-like) deposit on nozzle end of temperature valve; no corrosion.**
- 12. Fuel pump S/N PE2552X - No corrosion or wear; visually OK.**

**APPENDIX VI
PRELIMINARY REPORT,
LM100 FIRST-STAGE TURBINE BLADES**

RESULTS

Blade	View	Condition			
		AD (mils)	IGO	TFC	GO (mils)
#1 (uncoated)*	C/S	0.2	None	None	0.5
	L/E	0.5	None	None	1.0 - 1.5
#2 (coated)**	C/S	Trace	None	None	0.5 - 1.0
#3 (uncoated)***	C/S	0.5 - 0.6	None	None	1.0
	L/E	2.0	None	None	2.0

*(1) No appreciable sulfidation

(2) Contour irregular

** (1) C/S: 1.0 mil coating

(2) Surface - regular

(3) No appreciable sulfidation

*** (1) C/S and L/E: irregular surface indicative of erosion

(2) No appreciable sulfidation

CONCLUSION

The general condition of all three blades was good.

APPENDIX VII
SPECTROGRAPHIC ANALYSIS

Engineering Department
Materials Development Laboratory Operation
Analytical Chemistry Unit

SUBMITTED BY P. Linko K148
NAME ORGANIZATION BLDG. EXT.

DATE REC'D 8-24-67 DATE REPORTED 8-28-67 ACCOUNT NO. MYD02

SAMPLE HISTORY & MATERIAL DESCRIPTION Materials on T58

Secondary Fuel Nozzle Run on Emulsified Fuel

3319A - Red Deposit

3319B - Loose Material on Screen

TYPE OF ANALYSIS DESIRED: SEMI-QUANTITATIVE
QUANTITATIVE QUALITATIVE X

REPORT OF ANALYSIS: MAJOR = 100-10%; MINOR = 10-1%;
TRACE (T) 1-0%

	3319A	3319B		3319A	3319B
Ag	O	T	Mn	T	T
Al	T	Minor	Mo	O	O
B	O	O	Na	O	O
Ba			Ni	T	Minor
Be	O	O	Pb	T	T
Bi			Si	T	Minor
Ca	T	T	Sn		T
Cb	O	O	Sr	O	T
Cd			Ti	T	Minor
Co	O	O	V	O	O
Cr	T	T	W		
Cu	T	T	Y		
Fe	Major	Major	Zn		T
K			Zr	O	O
Mg	T	T			

R. J. Yoder

APPENDIX VIII

FUEL ANALYSIS

The emulsified fuel submitted for analysis has been investigated and the following noted:

1. The emulsion was broken into two phases by the addition of acetone: an emulsifier phase and a JP-4 acetone phase. Subsequently, the acetone phase was separated again into two components: an α and a β phase.
2. The α and β phases were analyzed spectrographically. The JP-4 and acetone phases showed almost no contamination; the emulsifier phase showed a strong phosphorus indication.
3. The blue deposits on a nozzle of X-40 which were exposed to combustion gases of the emulsified fuel were examined by X-ray diffraction and spectroscopy. In X-ray, the deposits showed evidence (not very conclusive) that the scale contained cobalt phosphate. The spectroanalysis identified cobalt and phosphorus in the scale.
4. Samples of L605 and X-40 heated in contact with Na_3PO_4 at 1800°F for a short time (1/2 hour) showed a blue deposit. Normally, these alloys do not show these deposits at this temperature and time interval.
5. Samples of L605 and X-40 were heated in contact with emulsifier obtained from the emulsified fuel. After 1/2 hour at 1800°F , a blue deposit was observed. The samples of X-40 and L605 were sectioned. Pitting was observed under the coked emulsifier.

These data indicate that:

1. The emulsifier in the emulsified fuel contains phosphorus, but its precise mode of chemical composition is uncertain. As the emulsifier had not appeared in the acetone phase, it must be polar in character. An organic phosphate compound would behave in this fashion.
2. The presence of phosphorus in the oxidation scale of the nozzle is unusual.

3. Inorganic compounds and the emulsifier both corrode L605 and X-40 but to different degrees, the inorganic salt Na_3PO_4 being the most corrosive in the short test.
4. The smaller the concentration of phosphorus, the slower the corrosion; but without phosphorus, the presence of the blue oxide in a short test time does not occur.
5. It is reasonable to assume that the heavy corrosion noted on the nozzle was caused by the phosphorus in the emulsifier.
6. Emulsified fuels per se need not be considered as corrosive, at least based on the data obtained in these tests. The culprit appears to be the type of emulsifier rather than the physical state of the fuel.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) General Electric Company Cincinnati, Ohio		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE FEASIBILITY OF BURNING EMULSIFIED FUEL IN A 7LM100 ENGINE		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (First name, middle initial, last name) W. W. Stockton C. M. Olsen		
6. REPORT DATE February 1968	7a. TOTAL NO. OF PAGES 70	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. DAAJ02-67-C-0038	8b. ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 67-74	
8c. PROJECT NO. 1F121401A529		
8d.	8e. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
8f.		
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY US Army Aviation Materiel Laboratories Fort Eustis, Virginia	
13. ABSTRACT Much investigation and aircraft engine operation have been accomplished in developing a "safe" fuel that will not explode in its stored condition when exposed to a spark, but which will give identical engine performance when used in place of fuels being burned today. The Bell air cushion vehicle engine, a General Electric LM100, was tested on the latest emulsified "safe" JP-4 fuel (WSX-7165). Engine starts and operation were about the same with emulsified JP-4 fuel as with plain JP-4 except that running time was limited on emulsified fuel because of fuel nozzle clogging. Clogging was caused by dirtier-than-normal fuel and by an iron deposit that formed on the fuel nozzles and fuel nozzle screens.		

DD FORM 1473

1 NOV 64

REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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Security Classification

